

**FOSSILS OF THE MILWAUKEE
FORMATION:
A DIVERSE MIDDLE DEVONIAN BIOTA FROM
WISCONSIN, USA**

Kenneth C. Gass, Joanne Kluessendorf, Donald G. Mikulic
and Carlton E. Brett

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DISCLAIMER: This book is a general guide to fossils of the Milwaukee Formation and not an extensive manual for health and safety when visiting this site. Furthermore, because potential hazards may change over time, prior to undertaking any fossil collecting activities, you need to make yourself aware of any RISKS, DANGERS, HAZARDS and LEGAL IMPLICATIONS associated with visiting and collecting fossils at any particular site. The publisher, authors or any associated parties cannot be held responsible for your failure to do so, nor any consequences thereof.

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In Memory of
Dr. Joanne Kluessendorf
(1949–2018)



Joanne Kluessendorf with cast of *Dunkleosteus*; December, 2017.
Courtesy of Beth A. Johnson and The Geological Society of America.

Preface

Over one hundred years have passed since H.F. Cleland wrote *The Fossils and Stratigraphy of the Middle Devonian of Wisconsin* (1911) — the first and only volume written largely on the Milwaukee Formation biota. Typical of similar works of its day, its illustrations were mostly black and white drawings. During the last century, new material has been gathered, many additional species have come to light, much has been learned, and advances in technology have made it possible to economically publish books having many full color photographs. Today around 250 species, subspecies, unnamed species and ichnospecies have been identified from the Milwaukee Formation, nearly 180 of which are illustrated in this book. These are represented by new and old material, including type and figured specimens wherever practical. Moreover, the large collections from this diverse biota have enabled a wide variety of fossil studies that depend on large sample sizes. It is our hope that this compilation of information and photographs will enlighten and entertain regional fossil collectors, spark the interest of researchers and budding paleontologists, and reach the hands of graduate students and professionals studying Devonian paleontology and others seeking fertile grounds on which to base their research, as offered in this much-neglected but diverse Middle Devonian biota.

Each major taxon of the biota is covered in its own chapter. Each of those chapters includes a discussion of that taxon and in most cases photographs of representative Milwaukee Formation fossils labeled to show important observable morphological features. The chapter then presents photographs of many of the species identified within that major taxon. The names of the other species of that taxon known to exist in this formation but not shown are listed. Terms that are introduced but not defined in the text are defined in the Glossary. Sections on stratigraphy, Milwaukee's cement industry, paleoenvironments, modes of life, organism interactions, taphonomy, fossil collecting in the Milwaukee Formation, preparation methods, and major collections round out the discussion.

Whenever known, the collectors of the fossils shown are indicated with their initials in the figure captions. The identities of those collectors are as follows: Benedict Bagrowski (BB), Elmer Dahlman (ED), Ira Edwards (IE), Marlene O. Emielity (MOE), Damien K. Gass (DKG), Jeanette L. Gass (JLG), Joshua S. Gass (JSG), Kenneth C. Gass (KCG), Kevin M. Gass (KMG), Lauri A. Gass (LAG), Todd C. Gass (TCG), Thomas A. Greene (TAG), Spence Havlick (SH), Thomas James (TJ), Ronald Kneusel (RK), Thomas Maier (TM), Donald G. Mikulic (DGM), Milwaukee Cement Company (MCC), Charles E. Monroe (CEM), Gilbert O. Raasch (GOR), Jeannette E. Roberts (JER), H. Rollins (HR), Lindsey V. Stenerson (LVS), Karly S. Tellekson (KST), Edgar E. Teller (EET), and Stanley Wisniewski (SW). The collectors of the specimens residing in the Greene Geological Museum were typically not recorded in the museum catalogs, but were either Thomas A. Greene, various Milwaukee Cement Company workers, or others.

Classification, descriptions and morphological terminology for invertebrates generally follow the current editions of the appropriate volumes and parts of the *Treatise on Invertebrate Paleontology. Fishes of the World, Fifth Edition* (Nelson et al., 2016) was similarly an indispensable resource for fishes. The generic placement of many species has been updated based on the most recently published studies and consultation with various specialists. Identifications should be considered tentative and targets for future investigation. Due to the tentative nature of the identifications, diagnoses are not given.

Prefixes of specimen numbers given in the figure captions indicate the respective repositories, as follows: MPM=Milwaukee Public Museum; UWM-GM=Greene Geological Museum, University of Wisconsin—Milwaukee; V or PAL=National Museum of Natural History, Washington, D.C.; VPF=Museum of Comparative Zoology, Harvard University; WESM=Weis Earth Science Museum, Menasha, Wisconsin. The prefix XXX-KCG indicates that the specimen resides at the indicated museum, but the catalog number is that given by KCG and not by the museum. Higher taxonomic placement of the species shown in each photograph, typically order and family, are stated in the corresponding figure caption (e.g., Arthrodირiformes:

Dunkleosteidae). If the figure caption does not state where the fossil was found, the specimen was collected either at one of the quarries near the Milwaukee River in northeastern Milwaukee County (mainly those operated by the Milwaukee Cement Company), or from Estabrook or Lincoln Park. Unless otherwise indicated, the photographic work was that of KCG.

KCG, DGM and JK are indebted to the late Joseph G. Emielity, Katherine G. Nelson, and Gilbert O. Raasch—each being curators of Milwaukee Formation fossils—for their friendship, for sharing their wealth of knowledge, and for solidifying our interest in this subject. Richard Fortey is thanked for reviewing a draft of the manuscript, especially the introductory and arthropod chapters, and providing useful input. We thank the following for reading drafts of the section on the indicated group of organisms and/or examining photographs of that group and providing valuable input: Robert K. Carr (fishes); Brian Chatterton and James Cook (trilobites); Jed Day (brachiopods); Andrej Ernst (bryozoans); Paul Kenrick (land plants); David Loydell (graptolites); George McIntosh (blastoids); Colin Sumrall (edrioasteroids); Heyo Van Iten (conulariids); Olev Vinn (tentaculitoids); and Brian Witzke (crinoids). A special thank you goes to Patricia Coorough-Burke for open access to the material at the Milwaukee Public Museum and providing much information and support. We are indebted to Stephen Dornbos and his staff (Greene Geological Museum) and the late Joanne Kluessendorf (Weis Earth Science Museum) for access to the collections in their respective museums and accommodating our needs. Amanda Millhouse and Kathy Hollis (National Museum of Natural History) and Jessica Cundiff (Museum of Comparative Zoology) are thanked for photographing material in their respective museums. Linda Deith (The Wisconsin Geological and Natural History Survey), Emma MacPherson (Canadian Society of Petroleum Geologists), and Beth A. Johnson are thanked for permission to use the indicated published images. Robert K. Carr, Terry C. Grande, and Joanne Kluessendorf are thanked for allowing us to publish figures based on their drawings. Lisa Marine (Wisconsin Historical Society), Jennifer Pahl (Milwaukee Public Library), and Susan Peschel (American Geographical Society Library, University of Wisconsin-Milwaukee Libraries) are thanked for providing scans of images and other materials in their care. JK and DGM thank the Wisconsin Historical Society for use of their archives. We also thank Denise Baker for help with Word issues; Richard Bizley for painting the cover image; David Bradbury for helping locate specimens; David Comfort for preparing certain fossils; Niles Eldredge, Gerald Kloc, and Bruce Lieberman for helpful discussions on phacopid systematics; Curt Klug for years of collecting trips with DGM and JK; Todd Gass for providing hardware and software support and for helping process some of the images; Ron Kneusel for suggesting that the book be written; J. Maisey for verifying the identity of the shark fin spine; and Dietmer Schumacher for providing conodont preparation methods and permission to use his published images. Finally, we thank David Penney of Siri Scientific Press for extending the opportunity to publish this work and for making improvements.

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Chapter 28 — The Cement that Made Milwaukee Famous

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Weis Earth Science Museum

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Milwaukee, Wisconsin is well known historically as a center of American industry and commerce. During the late 19th and early 20th centuries, it was the home of some of the more prominent manufactories and breweries in the country. Largely forgotten however is its role as one of the leading late 19th century cement producers in the United States (Fig. 333). From 1876 until 1911 the Milwaukee Cement Company dominated the Midwestern cement market through the manufacture of Milwaukee Hydraulic Cement, then considered to be the best natural cement in the country and recognized as the standard for use in federal government and other municipal projects (Kluessendorf & Mikulic, 2008). From large modern plants along the Milwaukee River, Milwaukee Hydraulic Cement was shipped over a vast region extending more than 1200 miles from "Detroit and Cleveland on the East to Kansas City and Denver on the West" (Greene & Berthelet, 1949) and from Canada on the north to Kentucky on the south. Although this enterprise had considerable economic importance in Wisconsin, it also contributed to important scientific and educational interests. Primarily through the excavation of cement rock at the Milwaukee Cement Company's quarries and mines, a unique opportunity existed to make large fossil collections and conduct scientific research on the Middle Devonian rocks of the Milwaukee Formation. As a result of the large-scale quarrying along with the rarity of Devonian rocks in the region, Milwaukee was at the time one of the most important sites for scientific studies on the Devonian in the Midwest. Without the activities of this industry, much less would be known about the geology and paleontology of the Milwaukee Formation, and this book would probably not have been written. This chapter discusses how the region's geology and settlement, combined with changing technology and economic conditions, first created and then destroyed a major industry.

Stone for construction

During the early 19th century, wood was relatively well distributed and clay used in brick making could be found in many communities, but sources of stone needed to manufacture critical construction products such as cement, lime, and building stone were for geologic reasons few and far between. In addition, with the availability of only simple excavation equipment, it was difficult to produce stone resources on a large scale, and the poorly developed transportation systems of the time made shipping of these heavy and bulky commodities very difficult, expensive, and in some cases impossible. As a result, during much of the 1800s, only local sources of these critical stone based materials were available throughout much of the Midwest and when found, they were used regardless of their quality.

Early 19th century Milwaukee is a typical example of the geologically restricted distribution of these types of mineral resources. As a place where the bedrock surface is generally buried by thick deposits of unconsolidated Quaternary sediments, it was difficult for most early settlers to find nearby rock exposures where they could quarry or purchase stone construction materials. Building stone and lime were commercially produced in the region but only at a limited number of geologically controlled and irregularly distributed locations. The poorly developed roads of the time along with the lack of railroads in the area presented problems in moving these materials even over short distances. While lime and building stone were usually available at many sites in southeastern Wisconsin, initially there was no cement manufactured from local resources. Without cement, lime mortar was the primary binding material used in construction. If a person wanted to build a brick or stone building, lime mortar was a more economical and widely distributed alternative to importing cement from great distances. It was relatively easily made requiring less experience and equipment to manufacture. For example a farmer with access to almost any kind of limestone could with limited experience and investment build his own kiln and using local wood burn all



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With superior facilities for the prompt, safe and cheap shipment of our celebrated brand of HYDRAULIC CEMENT, we are able to meet every demand upon us on your part promptly, and, we believe, to the satisfaction of all.

Contractors to the United States Government for furnishing 100,000 barrels of Milwaukee Cement used in their extensive construction at Sault Ste. Marie.

MILWAUKEE CEMENT CO.

Fig. 333. Advertisement for the Milwaukee Cement Company from Anderson & Bleyer, 1892.

of the lime he needed for mortar. It was even possible to burn limestone glacial boulders in a pit dug into the ground to make lime. Manufacturing cement, however, requires rocks with a very specific composition which usually have a very geologically limited distribution. In addition, cement can only be manufactured in more complex and expensive facilities which requires a crew of knowledgeable individuals to operate and generally used coal as a fuel. For these reasons lime kilns were a common feature throughout much of the 19th century Midwest, while cement plants were very rare. As larger and more durable buildings along with other structures were being built during the late 1800s, lime mortar became less suitable as a binder and, as a better replacement, the need for cement in large scale construction projects greatly increased. As a result, the geologic controls on the availability of the stone resources needed to manufacture cement became more important. The closest cement producing locations to Milwaukee were at Utica, Illinois and Louisville, Kentucky. However, with the lack of a good land-based transportation system during the first half of the 19th century, cement, even in small amounts, could not be shipped cheaply over land to Milwaukee from either place. Instead limited and still expensive supplies of cement were imported by boat from more distant eastern locations on the Great Lakes such as New York. Until railroad transportation became available, true cement was probably a rarely used building material in Milwaukee.

The discovery of cement rock was economically important for Milwaukee area construction as local cement production greatly lowered the shipping cost of this critical building material, while it also became the basis of an important export commodity. Geology played a critical role in how Milwaukee's cement rock was discovered and how the industry developed. The "limestone" (actually dolomite or dolostone, which is a magnesium rich carbonate rock) of the Middle Devonian Milwaukee Formation, only occurs in a small area of northern Milwaukee County (Fig. 334), and continues east beneath Lake Michigan (see Chapter 2 for details on the geology of the Milwaukee Formation). As true throughout most of eastern Wisconsin, the bedrock surface in Milwaukee County is generally buried beneath a thick blanket of unconsolidated Quaternary glacial or lake sediments. Natural outcrops of the Devonian age rocks in this area were therefore rare and small in size but had been known for centuries. As early as the 1670s, French visitors to the region reported finding scattered rock exposures containing "pitch" (natural asphalt) along the Lake Michigan shore near present day Milwaukee. They used this material to caulk their canoes. It is possible that they were referring to an exposure of the Milwaukee Formation which contains asphalt, and can still be seen at Whitefish Bay (Thwaites, 1900). No other rock outcrops containing asphalt are known along the Lake Michigan shore of Wisconsin. In the 1830s, at the start of local European settlement, outcrops of the same rocks were also found extending for almost a mile along the Milwaukee River between what is now Capitol Drive and Hampton Avenue. Here much of the river flowed directly on the bedrock surface with a few low outcrops occurring along the river banks. Initially a few quarries were opened in this area to produce lime or building stone, but the clay content of the cement rock was too high to make good lime and it was too thin bedded and soft to produce good building stone. Although inferior in the quality needed to make these common stone products, it was found later that these rocks had excellent properties needed to make natural cement. In geologic literature and fossil collection catalogues, the outcrops and quarries in this area are referred to by a variety of names including: Humboldt, Lindwurm, Berthelet, Cementville, Milwaukee River, and Milwaukee.

Natural cement

Milwaukee Hydraulic Cement is a natural cement which differs in several important ways from the Portland (artificial) cement that is now universally used in construction. Natural cement is made by calcining (burning at a high temperature) argillaceous (having up to 25% clay minerals) carbonate rocks such as limestone (CaCO_3) or dolomite in a kiln which changes its chemical composition by driving off carbon dioxide. The resulting clinker (CaO) is then ground into a fine powder making natural cement. Adding water to the cement will cause it to harden through reversing the chemical process and when mixed with aggregates such as crushed rock will make concrete. During much of the 19th century, natural cement rock was the source of most of the cement used for heavy construction in the United States. While many carbonates are argillaceous, only a few have the correct carbonate to clay ratio and mineralogy needed to produce

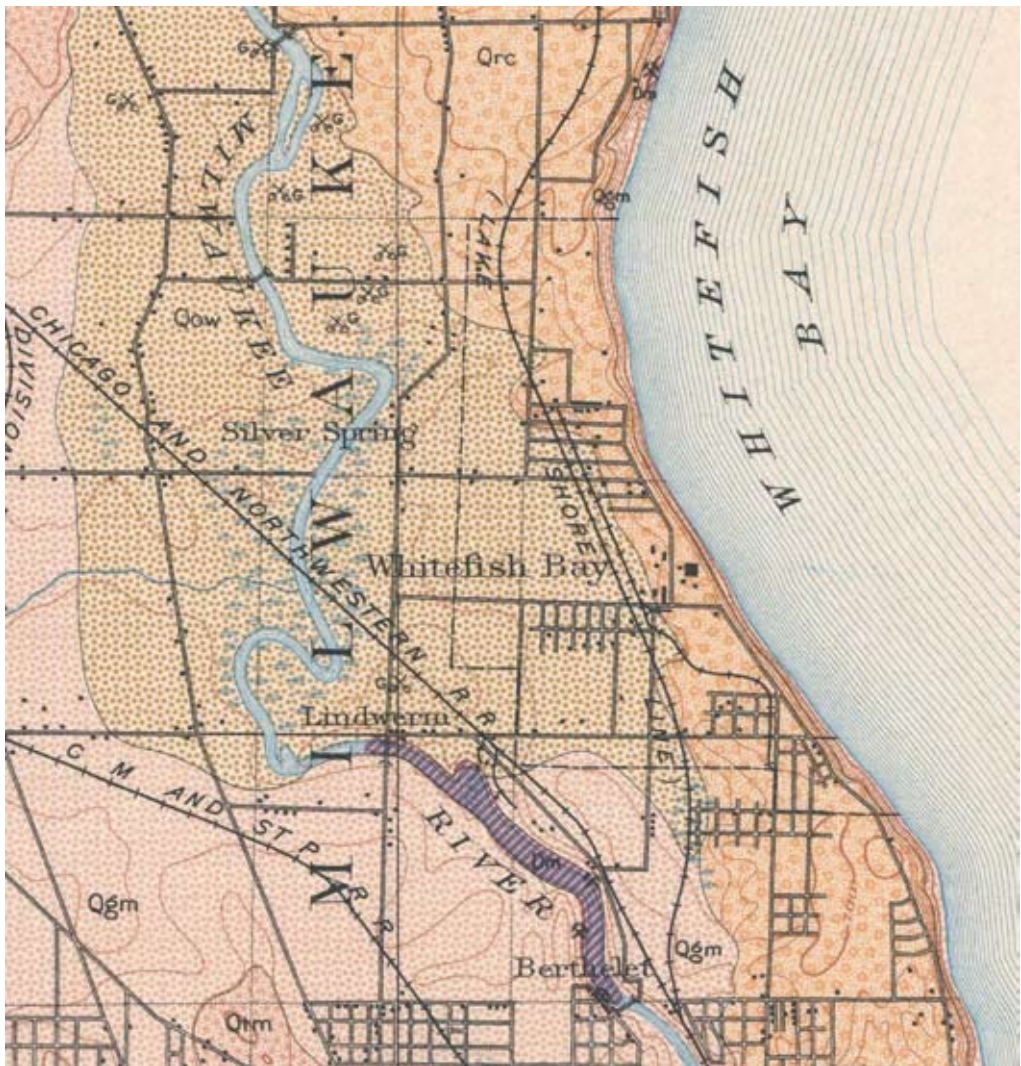


Fig. 334. Areal geology of a portion of northeastern Milwaukee County. Purple striped areas (labeled Dm) portray locations along the Milwaukee River and the Lake Michigan shore at Whitefish Bay where the Milwaukee Formation occurs at or near the ground surface. From Alden, 1906.

a good cement. The argillaceous component of natural cement gave it an important characteristic as a hydraulic (water lime) cement and it will set under water. This is in contrast with non-hydraulic cements such as the commonly used lime mortar which was a cheaper, more easily made, and a widely available binding material. Although natural cement rock was the primary cement of the 19th century, during the early part of the century experimentation in Europe had led to the development of Portland (artificial) cement in which a clay free limestone/dolomite is artificially combined with clay or shale before calcining. This process produces a higher quality hydraulic cement compared to that made from natural cement as many of the former's characteristics can be altered and controlled while those of the later cannot. Although it had superior qualities, the use of Portland cement only slowly replaced the use of natural cement towards the end of the 1800s. In general, Portland cement had higher manufacturing and shipping costs which limited its use, and there were few places where, for geological reasons, the correct types of limestones and shale could be found in close proximity to a cement plant. It was only with the use of rotary kilns, which provided a more uniform and efficient way of burning of the rock, along with improved transportation systems, that

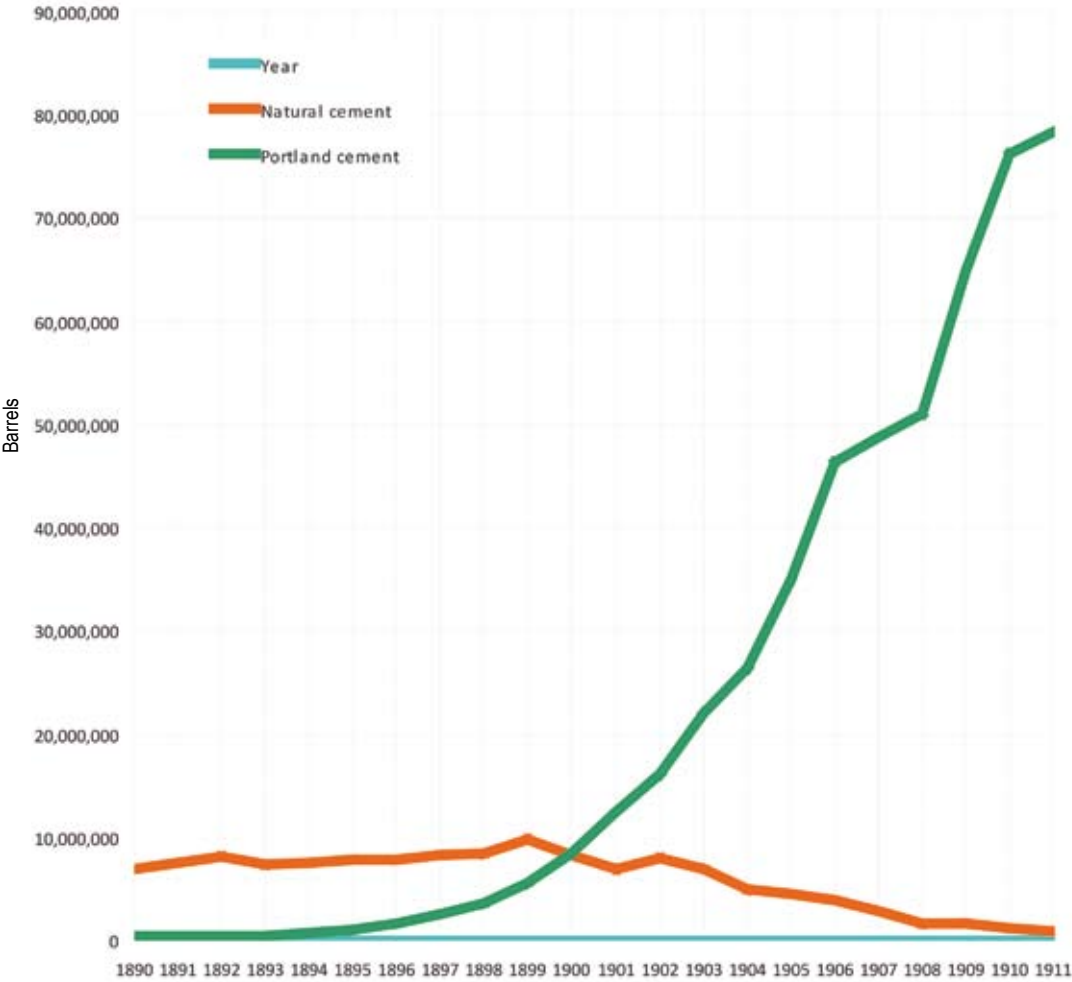


Fig. 335. Growth of the cement industry in the United States between 1890 and 1911. During this time interval, natural cement production leveled off and then declined while the use of Portland cement experienced astronomical growth in part by replacing the use of natural cement, but primarily through the rapidly expanding use of cement in concrete. The largest of these new uses included construction of road pavements, as motor vehicle traffic increased, along with the use of concrete blocks and poured concrete in general construction, thus changing thousands of years of building stone use. After Burchard, 1912.

it became more economical to manufacture Portland Cement and ship it to more distant markets. In a few short years of the late 1890s, the use of Portland cement skyrocketed while natural cement rapidly declined (Fig. 335). More specific to this story, Milwaukee Hydraulic Cement was driven off of the market.

Geology and mineral resources

The availability of mineral resources is controlled to a large extent by geological factors, which is demonstrated well by the development of the natural cement industry of the Milwaukee region. These factors including the depositional character of the bedrock, the persistency of these characteristics regionally, the structural configuration, and elevation of individual beds, along with the character and thickness of the overburden, all impacted the availability of cement rock in this area during the 19th century. Most important for any mineral resource is the character of the rock itself. Having the specific chemical composition in the correct proportions to make good natural hydraulic cement was the primary control on the value of this resource. Not all of the Milwaukee Formation made good natural hydraulic cement, however, and although

the formation is over 60 feet thick, only its lower 21 feet could be used as cement rock. Most of the upper beds of the Milwaukee Formation are still only known from deep subsurface borings or temporary rock excavations which all show that there is significant stratigraphic variation within the formation (Raasch, 1935; Mikulic & Kluessendorf, 1988a; 1988b, 1998; Kluessendorf, Mikulic & Carmen, 1988). The cement rock strata of the Milwaukee Formation (Beds 1–11 of Teller, 1901; A and B zones of Cleland, 1911), which are equivalent to the Berthelet Member of Raasch (1935), are limited to the bottom 21 feet of the formation and were only exposed in their entirety when the cement quarries were in operation. Even with the correct composition, however, it was fortuitous that a few feet of these strata which were historically exposed in limited natural outcrops were recognized as a cement rock source and were later commercially quarried for that purpose.

Most of the property along the Milwaukee River from modern day Capitol Drive northwest to Hampton Avenue was eventually purchased by the Milwaukee Cement Company, but for geologic and economic reasons, only a limited area of this land was ever quarried or mined. Quarrying did occur where there was a thick deposit of cement rock at or near the bedrock surface which was exposed at or near the river bed in the Milwaukee River valley. This would combine a maximum thickness of cement rock with a minimal thickness of overburden making the quarrying of cement rock relatively easy and economical. In general, the cement rock of the Milwaukee Formation underlies a large area in northeastern Milwaukee County, but usually is deeply buried by Quaternary age unconsolidated glacial and lake sediments. The area around Estabrook Park presents a unique situation however, as the Milwaukee River has locally cut through tens of feet of unconsolidated sediments down to the bedrock surface exposing the top of a thick interval of cement beds which could then be quarried. The bedrock surface here is actually higher than is typical for much of the region and marks the location of a buried bedrock hill that is rising towards the northwest. Further complicating this geology but representing a key factor in the availability of the cement rock is a structural feature that has tilted the normally horizontal rock strata downward to the southeast in a syncline and upward to the northwest (Mikulic & Kluessendorf, 1988a). This relationship can be observed by plotting the changing elevations of the cement rock through the park area. At the southern end of the park near Capitol Drive, the rock surface was never exposed in outcrop and is deeply buried (100ft.). Although the cement rock found here has a thickness of over 20 feet, economic mining at that depth was beyond the technology of the time. At the “falls” further upriver, the top of the 20-foot-thick cement rock has risen about 80 feet and is at river level but covered by about 10 feet of overburden away from the river. Continuing up westward there is an interval where no rock is exposed along the river but at the Estabrook Park dam site the Thiensville Formation, which underlies the Milwaukee Formation cement rock, outcrops at the bedrock surface which is about 5 feet higher than at the “falls”. Nearly all of the cement beds have been eroded away here but they formerly occurred at an elevation 20 or more feet higher than the current bedrock surface. Away from the river 10 or more feet of overburden overlies the rock surface. From the dam area northwest past the Port Washington Street bridge, these rock units change very little in elevation and with little or no Milwaukee Formation remaining, the Thiensville Formation generally occurs at the bedrock surface. Although the cement beds show considerable changes in elevation over this distance, their consistent uneroded thickness and their generally consistent lithologic character makes it an excellent source rock for cement manufacturing.

Geologically the Milwaukee Formation cement beds were deposited on a relatively level shallow sea floor during the Middle Devonian Period (390,000,000 years ago), which accounts for their consistence in composition. The 100-foot change in elevation of these beds between Capital Drive and the Estabrook dam site was the result of more geologically recent tilting of the bedrock and these beds were uncovered later through post Ice Age erosion by the Milwaukee River. From a mineral resource perspective, these beds underlie many tens of square miles in this part of Milwaukee County, but this is the only location in the region (from the southern end of Mill # 2 north towards the “falls” in Estabrook Park) where a significant volume of cement rock could be economically quarried during the late 19th century for the manufacture of natural cement.

The origins of the Milwaukee cement industry

The discovery of Milwaukee's natural cement rock began with geological research starting in the 1830s. Increase Allen Lapham, Wisconsin's first resident scientist (Hays, 1995; Bergland & Hayes, 2014), had begun to study the local geology of the area when he moved to Milwaukee in 1836 (Mikulic, 1983). Previously he was employed as a construction engineer on the Louisville and Shippingport Canal and had at the age of 17 published a paper (Lapham, 1828) on the geology of the canal area around Louisville, Kentucky. In this paper, Lapham described the characteristics of several rock units exposed in the vicinity of the canal, one of which he identified as "water lime rock" which when calcined forms a cement "which has the property of setting very hard under water" (Lapham, 1828). In an unpublished original manuscript titled *Geology of Milwaukee County* written between 1844–1848 (Lapham papers, Wisconsin State Historical Society), Lapham described both Lake Michigan shore exposures and Milwaukee River outcrops as belonging to the same stratigraphic unit and commented on their natural cement potential (Mikulic & Kluessendorf, 1998). In describing these Milwaukee rocks, he noted "The color, fracture, texture of this rock, as well as many of the petrifications are the same as that of the Water limestone at Louisville, Ky; and its geological position is the same, being next above the ["Cliff"] geodiferous limestone." On a following page he further stated, "Some layers of this limestone upon being burnt prove to be hydraulic lime, would not slack but when pulverized and made into a paste would harden under water as readily as the best hydraulic cement from New York." [This last page is undated, seems to be in different handwriting, and may have been a later addition to the manuscript]. Lapham published his first stratigraphic section of the Wisconsin Paleozoic rocks in 1851, where he correlated the limestone found along the Milwaukee River located north of the community named Humboldt and the Lake Michigan shore outcrops at Whitefish Bay with those of the "corniferous limestone of Eaton" in New York. In discussing the corniferous limestone, he stated, "Hydraulic limestone is found associated with it at Louisville and other places" (Lapham, 1851). In his last geologic publication (Lapham, 1876), he stated that "some of the layers appear to be of the same age as the water-limestones of Louisville Ky., and may have the same useful quality."

When in 1873 Lapham became the Chief Geologist of the Geological Survey of Wisconsin, a special effort was undertaken to investigate the cement potential of these rocks (Chamberlin, 1877, 1878). It is clear that Lapham had long known that these Milwaukee area rocks had the same basic characteristics of other Devonian age hydraulic natural cements already in production. It wasn't until the 1870s however, that Joseph R. Berthelet, Sr. also recognized the natural cement possibilities of the rocks along the Milwaukee River and decided to go into the cement business. Berthelet was co-owner of H. Berthelet & Company, a Milwaukee manufacturer of cement sewer pipe, and had been using hydraulic cement manufactured near Louisville in his business (Greene & Berthelet, 1949). Familiar with the characteristics of the rocks used to make Louisville cement, he was able to recognize that a locally collected rock sample he saw in the Milwaukee city engineer's office had the same appearance. He further realized that if this specimen represented a local source of cement rock he could save much of the transportation costs incurred by shipping Louisville cement to Milwaukee for use in his business. The often-cited story that the rock specimen Berthelet saw was from excavations for the North Avenue bridge in Milwaukee (Berthelet, 1942; Greene & Berthelet 1949) is untrue. It is now known that the bedrock surface is too deep (80 feet) at the bridge site to have excavated any rock, and that the specimen Berthelet saw was a rejected sample from the Milwaukee River outcrops to the north which had been submitted to the city by a contractor for possible use in the bridge's masonry. Exploring along the river Berthelet found and sampled the outcrops of the rock that Lapham had earlier studied and began a series of tests to determine if the rock would make a high-quality natural cement. Satisfied with his results, he then had Don J. Whittemore, chief engineer of the Chicago, Milwaukee, and St. Paul Railroad, conduct additional tests that eventually numbered nearly three thousand over the following year and a half (Langson, 1877). Whittemore was able to further confirm that the Milwaukee cement rock made high quality cement and determined, "that the cement produced from this stone is far superior in all the essential qualities of hydraulic cement to any other article of the kind in use at the present time" (Langson; 1876). Whittemore had previously (Whittemore, 1875) presented an extensive report on his work and stated:

"In conclusion, it gives me great pleasure to say to you, that this remarkable deposit of natural wealth is apparently abundant; that it lies in the bed and along the banks of our Milwaukee river, in the immediate vicinity of Washington bridge, not over a mile and a half from our city limits, in close to one or more of our trunk railway lines, and occupies a region of the river particularly noted for the beauty of its natural scenery. I congratulate you, moreover, upon the probability that, under the auspices of the enterprising gentlemen residing in this city who own the property, that this rock is likely to contribute largely to the general prosperity of Milwaukee." He further proposed to name this cement "Milwaukee Hydraulic Cement."

The Milwaukee Cement Company

Even before testing was completed, Berthelet and his associates including John Johnson, Henry Berthelet, and George H. Paul, began to purchase land along the Milwaukee River in order to open a quarry and erect a cement plant. What had started as an opportunity to reduce the expense of importing the Louisville cement Berthelet used in his cement pipe business, had rapidly become a plan to supply cement for the entire Milwaukee region. To finance this project, he gathered several key investors who eventually raised a capital of \$350,000. Throughout much of its existence, many of these same individuals would remain connected to the company as investors, directors, or employees including: Joseph R. Berthelet Sr., Joseph R. Berthelet Jr., George H. Paul, John Johnston, Henry Berthelet, Don J. Whittemore, William T. Berthelet, Thomas A. Greene, Howard Greene, Henry Campbell, George S. Bartlett, William Plankinton, and Samuel Marshall. Of these individuals, Thomas A. Greene was one of the more interesting although he initially had no connection to the company. As co-owner of Greene and Button, a prominent Milwaukee area wholesale drug business, Greene was a successful local businessman (Greene & Berthelet, 1949). He also was a prominent local gentlemen naturalist, with a long interest in geology. Late in life Greene began to collect local fossils as a doctor-ordered way to relax from pressures of business (Mikulic, 1983; Kluessendorf & Mikulic 1993; Kluessendorf & Mikulic, 1997; Mikulic, 1991). His attention quickly focused on the newly opened Milwaukee Cement Company's quarries, which were the only significant source of Wisconsin Devonian fossils. Becoming a regular fossil collecting and buying visitor to the quarries, he eventually purchased stock in the company (probably as a way of securing access to the quarries), and later became one of its directors. His collection of the cement quarry fossils is probably the largest and one of the most important ever made and is now part of the Greene collection at the University of Wisconsin-Milwaukee. After his death in 1894, his son Howard Greene took over his father's position in the cement company continuing a multi-generational family association with that institution like that of the Berthelet family. Long after it had ceased producing cement, Howard Greene and William Berthelet served as the last officers of the company. Through most of the existence of the Milwaukee Cement Company, members of the Berthelet family also continued to operate H. Berthelet & Co. in an adjacent office to that of the Milwaukee Cement Company office on Water Street in Milwaukee.



Fig. 336. Letterhead of the Milwaukee Cement Company circa 1890. View on left side shows Mill # 2 (left) and Mill # 1 (right). Note illustration of the prominent Milwaukee Formation fossil cephalopod *Gyronea eryx* between "Milwaukee" and "Cement" on right side, which was probably done at the suggestion of T.A. Greene.

On November 25, 1875, a charter was granted by the State of Wisconsin to the Milwaukee Cement Company and construction of the plant and kilns began in early 1876. Later that year the company began a three-decade period of almost continuous growth in which its production regularly increased and its operations were frequently modernized. At first sales of its cement focused on the Milwaukee area market, but as the company became a success and the superior qualities of its product were widely known, sales increased throughout the Midwest. For about 25 years the Milwaukee Cement Company remained highly profitable, regularly paying large dividends to its investors. This resulted in the company being regularly featured in local business promotional publications, and described in national building materials and engineering journals. At various times, it was noted to be the largest cement plant in the country and among the most modern in existence (Lewis, 1898). During the late 1800s and early 1900s, there also were numerous book, magazine, and newspaper articles describing success of the company and its operations (see Langson, 1876, 1877, 1879; Land, 1883; Barton, 1886; Langson, 1891; Bartlett, 1892; Lewis, 1898 [reprinted 1900]; Brown, 1901; Peckham, 1901). The 1949 historical article by Greene & Berthelet, reprinted with numerous illustrations and background information in *Natural News*, 2006a, 2006b, 2007, covers many of the business and administrative operations of the company that will not be repeated in detail here.

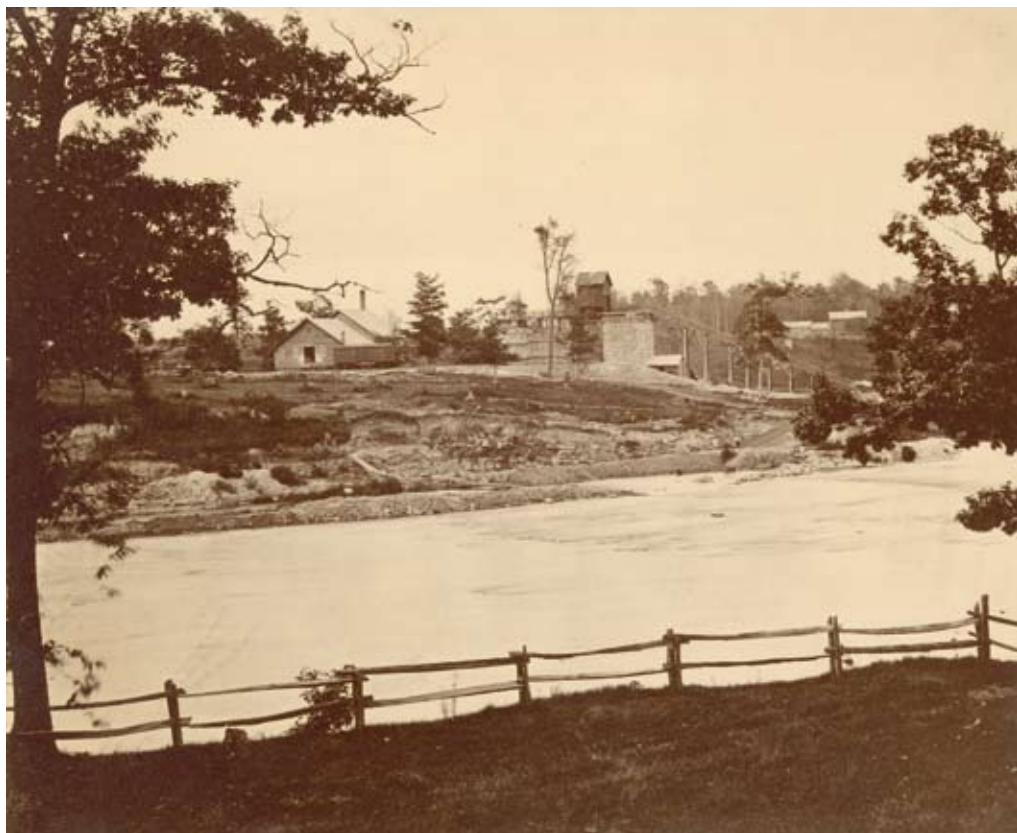


Fig. 337. The original plant (later Mill # 1) of the Milwaukee Cement Company showing the quarry in the foreground, two kilns in right center of photograph beyond the quarry, and the mill to west (left) of kilns. This view is looking north from the original south bank of the Milwaukee River. The plant was located in what is now Estabrook Park and east of the former railroad bridge site. The stage of kiln development indicates that this photograph was taken in the summer or fall of 1876. The photograph is part of a series by J.C. Miller including Figs. 339 and 340 in this publication. Used with permission of the Wisconsin Historical Society, WHS-142690.

The actual construction of its operations was started around May 24th, 1876, when workers “were directed to begin clearing the bedrock surface of overburden on a 50 by 100-foot area between the kiln site and river” in preparation for the quarrying of cement rock (Lohr, 1964). Construction of the adjacent kiln and mill (later Mill # 1) had begun earlier in the spring of 1876 (Greene & Berthelet, 1949). This plant and quarry area were located on the east side of the Milwaukee River, south of both the “falls” and rail spur (the course of the river generally runs from northwest to southeast through this area, but is usually described as running north-south) (Fig. 337). The “falls” is not a natural feature but the location of the north wall of the original quarry. The rail spur was built to the mill and kilns from the nearby Chicago & Northwestern Railroad (Northwestern Union) line providing a convenient method of shipping cement from the plant. A contemporary newspaper article (Milwaukee Daily Sentinel, June 23, 1876) provides a fairly detailed description of the initial operations at the company’s quarry and plant (later Mill # 1) along with some important geological observations. “About 100 feet west of the mill a quarry had been opened and there a dozen men were busy in digging out the stone. About four feet of surface clay was removed and the unbroken bed of rock lay bare”. The rock was in “layers about 2 feet thick, and blasting powder is necessary to loosen it.” After blasting “the stone is broken into pieces that a man can handle with ease” and loaded into quarry carts (Figs. 338 and 339).

The carts were then hauled on a tramway leading up to the top of the kilns, only one of which was then in operation with another under construction. The kiln was square, 40 feet high, 22 feet long and 20 feet wide with an egg-shaped interior that was 7½ feet in diameter at the top, 10 feet in the middle and 3 feet at the opening at the bottom (Milwaukee Daily Sentinel, 6-23-1876). Although the type of the materials used in kiln construction was not described, contemporary photographs (Figs. 337 and 340) indicate the outer walls were probably built with large dressed blocks of cement rock, while the internal lining of the kiln was probably made of fire brick. During operation, the kiln was filled regularly at its top with alternating layers of cement rock and coal. After continuously burning for twelve hours, the burned stone (clinker) had sunk to the bottom of the kiln and was ready for removal and grinding. From the kiln the clinker was transported on another tramway up into the mill building where it was processed through crushers before dropping down to the mill stones where it was ground into a fine powder. From there the powder was passed to a packing room where it was either placed in barrels or bags which were stored in a large warehouse before shipping to customers. This would be the basic system used by the company over the next twenty-five years, but it was regularly expanded and modified as its output rapidly expanded to meet increasing demand and new production technology was developed.

The Milwaukee Cement Company became well known as an innovator in the manufacture of natural cement and its plants were long considered to be the most progressive in the country. At the time of its opening, the mill turned out about 100 barrels of cement a day operating with a single kiln but by the end of the year it had produced 20,000 to 30,000 barrels of cement with 3 kilns in operation (Lanyon, 1877). After the 1876 opening of the original plant, expansion and innovation became a regular feature of the company. For example, in 1878, The Milwaukee Cement Railway Company was formed to extend the Chicago & Northwestern Road rail spur from the Milwaukee Cement Company plant west across the Milwaukee River to connect with the main line of the Chicago, Milwaukee, & St. Paul Railway. The noteworthy feature of this 1.19-mile extension was the construction of a bridge across the Milwaukee River having “three spans of ninety feet each, which with the trestle-work approaches, will give the structure a length of about 400 feet” (Milwaukee Daily Sentinel, 8-7-1878), which provided the company excellent connections with the regional transportation network. This short route was still in use by other firms into the 1990s when the bridge was finally removed and the line abandoned. Other early developments included a fifth kiln being erected which, in contrast with the earlier kilns, was circular in shape and encased in boiler iron; a style that all future company kilns would have, and a third warehouse was built with production reaching 12,000 to 15,000 barrels per month (Langson, 1879). To improve communication, a five-mile-long private telephone line was built in 1879 to connect the company’s Water Street office in Milwaukee with its plant on the Milwaukee River (Berthelet, 1942).

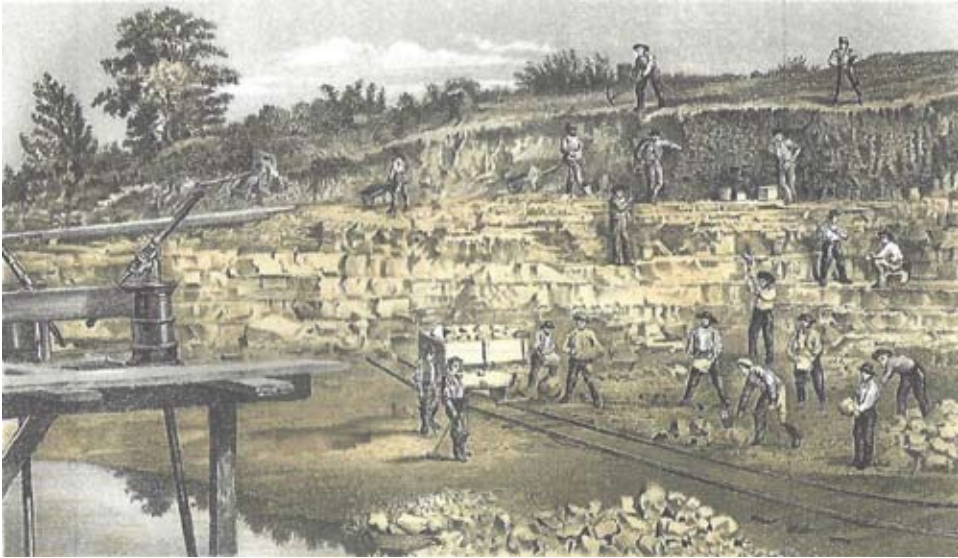


Fig. 338. An illustration from Chamberlin (Plate XIII, 1877, 1878), showing quarrying at the Milwaukee Cement Quarry in 1876. Included are depictions of the stripping of 5 to 10 feet of overburden above the cement rock, drilling and loading holes in the quarry wall in preparation for blasting, breaking blasted rock, and loading the rock into dump cars which were probably pulled by horses on a tramway to the kilns. The illustration also shows the significant increase of overburden that needed to be stripped as quarrying progressed away from the river and into the bluff. The mechanical structure on the left side of the illustration is probably a man operated water pump needed to keep the water level low in the quarry. This illustration was made by the Milwaukee Lithography & Engraving Company, and is based on a photograph (Fig. 339) taken by J.C. Miller during the summer or fall of 1876.



Fig. 339. The original 1876 photograph of the Milwaukee Cement Company quarry used as the basis for the illustration in Fig. 338. Photograph by J.C. Miller and used with permission of the Wisconsin Historical Society, WHS-142688.



Fig. 340. Photograph of the original Milwaukee Cement Company plant (later Mill # 1), showing the kilns (on left) with the mill and engine house (on right). Photograph by J.C. Miller and used with permission of the Wisconsin Historical Society, WHS-142686.

From a geological standpoint, it is interesting that while the cement rock had been extensively tested for over a year, information in this article indicates that the total thickness of the cement rock had not been determined when production started. Although the company had dug a few exploration holes, some of which were "16 feet deep," none had reached the bottom of the cement rock. The 1876 view of the quarry (Fig. 338) published in Chamberlin (1877, 1878) and original photograph on which it was based (Fig. 339) indicate that only about 10 feet of cement rock was then being quarried. At the time, the large property holdings of the company along with the modest planned scale of production suggested to many that the cement deposit was "inexhaustible" (Milwaukee Daily Sentinel, 6-23-1876); however, the rapid expansion of production in combination with the unrecognized geological limitations of the deposit would result in future supply problems.

The rapid success of the Milwaukee Cement Company probably attracted the early interest of other parties hoping to open competitive local cement plants even before any cement had been produced (Milwaukee Daily Sentinel, 6-23, 1876). However, the geology of the region greatly limited the occurrence of accessible deposits of cement rock. To try to prevent competition and insure their own supply of cement rock, the Milwaukee Cement Company attempted to purchase or control all of the land along the Milwaukee River where cement rock outcropped. After their initial purchases, the largest area of accessible cement rock remaining outside of their control was owned by the J.J. Orton estate. This property covered almost ninety acres on the west side of the river, and much of the land had a thick deposit of cement rock with only a thin covering of overburden, making it the best location for another quarry. By the mid 1880s the rapid growth of the market for Milwaukee Hydraulic Cement resulted in the company looking for ways to increase production. The availability of cement rock to quarry was a key factor in increasing production and

it could only be addressed by acquiring more land. The most obvious source of additional land was the Orton property. When the company attempted to start negotiations for its purchase, it was discovered that the Orton estate had already received an offer for the property from the newly formed Hadfield Cement Company. This company was incorporated by the Hadfield family of Waukesha on December 19th, 1885, even though they had not previously been in the business of manufacturing cement. The Hadfields were however one of the largest producers of lime and building stone in the Midwest and were actively trying to expand their business interests into other ventures such as coal and apparently manufacturing and selling cement. Although the Hadfield company was first to make an offer on the Orton property, it was not accepted and a much higher bid by the Milwaukee Cement Company was able to secure the site (Greene & Berthelet, 1949). In 1887, the company built its Mill # 2 (Figs. 341 and 342) and opened a new quarry on the Orton estate land. Initially this plant was operated on a royalty basis, but in 1890 the entire property was purchased outright by the company. With twenty kilns and a potential production of 2,500 barrels of cement daily, this plant had a larger output than Mill # 1 and was considered to be the largest individual cement mill in the country (Stickney, 1897). Lewis, (1898) described Mill # 2 in a detailed article and although it had a similar layout to the original 1876 plant, it was much larger and utilized a number of significant technological improvements which greatly increased its production (Fig. 343). Several of these improvements resulted from the work and designs of Milwaukee Cement Company personnel. Most notable were the Berthelet separator and the Campbell kiln (anonymous, 1897; Lewis, 1898) developed by J.R. Berthelet and H. Campbell, respectively. They were issued on patents on their inventions, which were also used in other cement plants around the country. With frequent improvements in production and as one of the newest cement plants in the country (Stickney, 1897), the Milwaukee Cement Company continued to be considered to be a leader in cement manufacturing.

The purchase of the Orton land provided an important opportunity for a major 1892 change in the Milwaukee Cement Company's operations, the results of which are still a prominent feature of the area today. After years of excavation, the Mill # 1 quarry only had limited space available for expansion, so as far back as 1880, the company had to undertake more expensive and less efficient underground mining to meet its production needs. By 1886 several tunnels had been dug into the east wall of the quarry lying between the kilns on the south and the railroad bridge on the north. No mine maps of this site are known, but the tunnels might have extended to the company's eastern property line. With the purchase of the Orton land, the quarrying of cement rock at Mill # 1 was shifted west across the river. This was accomplished by diverting the Milwaukee River eastward using the quarry of Mill # 1 as a new artificial river channel. The modern "falls" in the park at the north end of this channel is not a natural feature, but is the north end of the Mill # 1 quarry representing a manmade artificial waterfall. In 1893 Mill # 1 was remodeled which included building a combination iron trestle bridge and inclined tramway to the kilns across the newly rechanneled river (Figs. 343 and 344). The tramway provided a means to move all of the cement rock used in the kilns from a new quarry along the now dry old west bank area of the river. With the prior opening of the Mill # 2 quarry, all the cement rock quarrying was shifted to the original west side of the river (Figs. 343 & 344) and eventually both of these new quarries were joined making one large quarry which extended from Mill # 2 north past the railroad bridge.

In 1898, an article on changing the river course appeared in *Stone* magazine which was based on a story in *The Evening Wisconsin* newspaper.

"One of the most interesting things that has been done at the cement works is the changing of the course of the Milwaukee River for a distance of over half a mile. To the east of the old course of the river the rock was taken out and the quarries worked as far as they would pay. Then it was concluded that immediately west of the river was a fine bed of rock that could be worked to advantage if the river were out of the way. So, a dam was built about three-quarters of a mile below the Washington bridge and the river narrowed down to about half its former size. Then the water was sent through the worked-out quarries to the east of its original course. An embankment was raised between the old and new courses and now the old river



Fig. 341. Lithograph depicting Mill # 2 (on left) and Mill # 1 (on right) of the Milwaukee Cement Company. View is from the east side of the Milwaukee River looking towards the northwest. Note that the Mill # 2 quarry is limited in size and the river has not been directed into old quarry at Mill # 1 indicating the time period of this illustration was between 1887 when Mill # 2 was started and 1890 when the river was diverted. Courtesy of Historic Photo Collection / Milwaukee Public Library.



Fig. 342. Panoramic photograph showing, from left to right, the Milwaukee Cement Company Mill # 2, the quarry for Mill # 2, the Milwaukee Cement Company Mill #1, and the plant of the Cream City Cement Company. This view is from east side of Milwaukee River looking southwest. Note that the extensive quarry expansion at Mill # 2 (started 1887) and the presence of the Cream City Cement plant (demolished after 1894) suggests that the date the photograph was taken was in the early 1890s. Courtesy of Historic Photo Collection / Milwaukee Public Library.

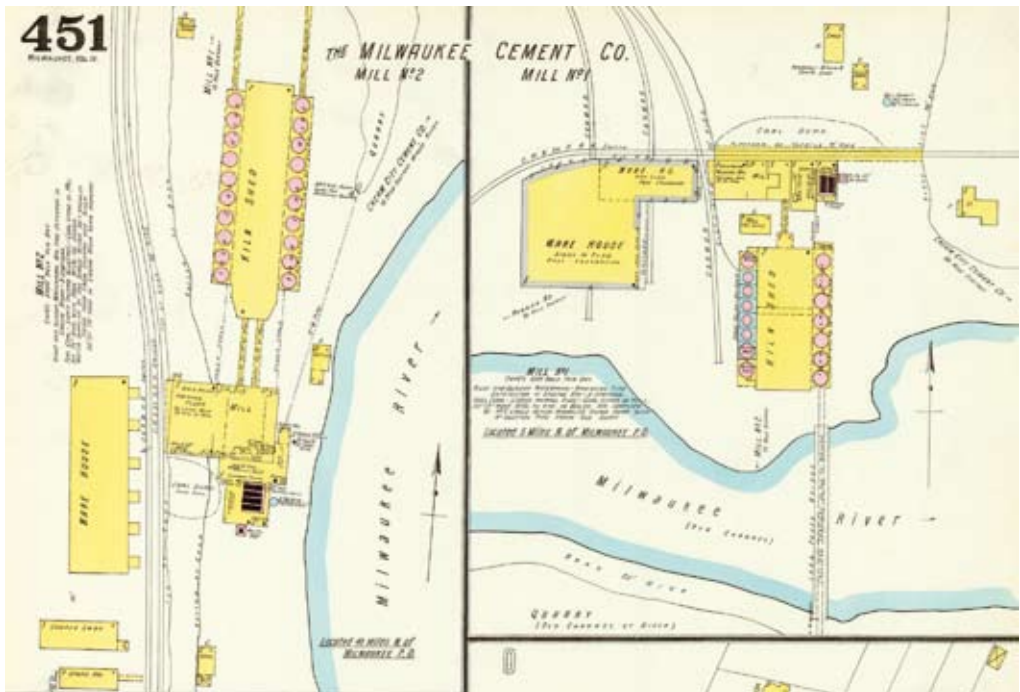


Fig. 343. Fire insurance maps of the Milwaukee Cement Company's Mill # 1 and Mill # 2 showing the layout of each plant and the primary materials used in the construction of buildings and other structures. From Insurance Maps of Milwaukee, Wisconsin, Volume Four, 1894, Sanborn-Perris Map Co., p. 451. Pink color indicates buildings primarily of brick construction, yellow is wood construction, and blue is stone construction. From the American Geographical Society Library, University of Wisconsin-Milwaukee Libraries.



Fig. 344. Milwaukee Cement Company Mill # 1 showing the remodeled 1893 plant, along with the new bridge and trestle across the Milwaukee River which had been rerouted through former Mill # 1 quarry. This view is looking west and possibly was taken from a building at the Cream City Cement Company plant. From a photograph in Views of the Cement Co.'s Works, Milwaukee, Wisconsin by the Milwaukee Cement Company, 1897. Used with permission of the Wisconsin Historical Society number, WHS-142689.

bed is perfectly dry. This change was made about a half a dozen years ago. Quarrying was commenced at the southern end of the dried-up bed and the stone has been taken out for a distance of about an eighth of a mile, and to a considerable depth." "In the neighborhood of the cement works the river is shallow for the most part, except where it runs through places where rock has been removed."

With both quarries and plants running, the Milwaukee Cement Company set new records of production yearly. Following the construction of Mill # 2 in 1887 and the remodeling of Mill # 1 in 1893, the company had thirty kilns in operation producing up to 500,000 barrels of cement and employing about 300 workers. Technological innovation and regular modernization (Figs. 345 & 346) resulted in one of the most productive cement operations in the country. By 1893 the Milwaukee Cement Company Mill # 1 had 10 kilns in operation and the company's operations were claimed to be the largest, most modern and complete hydraulic cement works in the world (Fig. 347). The company continued to have exceptional growth into the 1890s, with over 100,000 barrels produced by Mill #1 in 1880, over 200,000 barrels in Mill # 1 in 1884, over 300,000 barrels from Mill # 1 in 1887, and over 400,000 barrels of cement from 30 kilns in Mills # 1 and 2 combined in 1888. In 1896 more than 500,000 barrels of cement were produced in Mills 1 and 2, which might represent the company's largest production in a single year. When in 1888 Mill # 2 began operation, it was stated that it had a daily capacity of 2,000 barrels a day, which could make the yearly production for both plants at over a million barrels which "is far in excess of the demands" (Milwaukee Sentinel, July 7, 1888). Although production increased until at least 1896, the rate of increase slowed in the 1890s, possibly because of a weak economy following the Panic of 1893, but certainly because of the start of competition from a rapidly growing Portland cement industry.

Competition

After the Orton property was purchased, nearly all of the best locations for quarryable cement rock were owned by the Milwaukee Cement Company. There were other spots where cement rock outcropped in Milwaukee County which were not ideal geologically, but because of the high demand for and potential profitability of manufacturing Milwaukee Hydraulic Cement, they attracted the attention of other groups. Over time two other companies built cement plants, but because of the geological conditions at their locations, neither was successful.

The first was the Cream City Cement Company, which was incorporated in 1889 by a group of Milwaukee investors including George Brumder, a prominent local German newspaper publisher. The company built a large plant with five kilns on a piece of land along the east bank of the river which was so small that it apparently had escaped the interests of the Milwaukee Cement Company. Howard Greene (unpublished and undated manuscript) stated that the reason why the company hadn't purchased it earlier was that Berthelet didn't think the land had any value. This mistake would cause the company a lot of trouble. Located near the middle of the Milwaukee Cement Company property, this new plant site consisted of only about a three-acre triangular piece of land mostly located on the top of the river bluff between the Chicago and Northwestern Railroad tracks and the river. While this location had a good section of cement rock to work with, other significant geologic constraints made it difficult and expensive to do so. The site included virtually none of the river flood plain area that provided easy access to the cement beds while the land here was covered by more than 40 feet overburden. This parcel was part of a larger property of about 20 acres in total that extended to the north, none of which could be quarried from ground level, but it could be accessed by a vertical shaft with lateral tunneling extending from the plant site. To access its cement rock the Cream City Cement Company had to construct its kilns and plant on top of the bluff. It was then connected by a platform out and over the river flood plain to an elevator located over a mine shaft (Figs. 348 & 349). All of the cement rock produced on this site was mined underground and had to be transported up to the top of the bluff, which added significantly to production costs. The only description of what the inside of any of the local cement mines were like was given by Johanna Thomsen in a Milwaukee Journal article (Milwaukee Journal, 2-23-1960). Her husband was a worker at the Cream City Cement plant and in this article she remembered going down the elevator shaft to a tunnel where the men were working. The

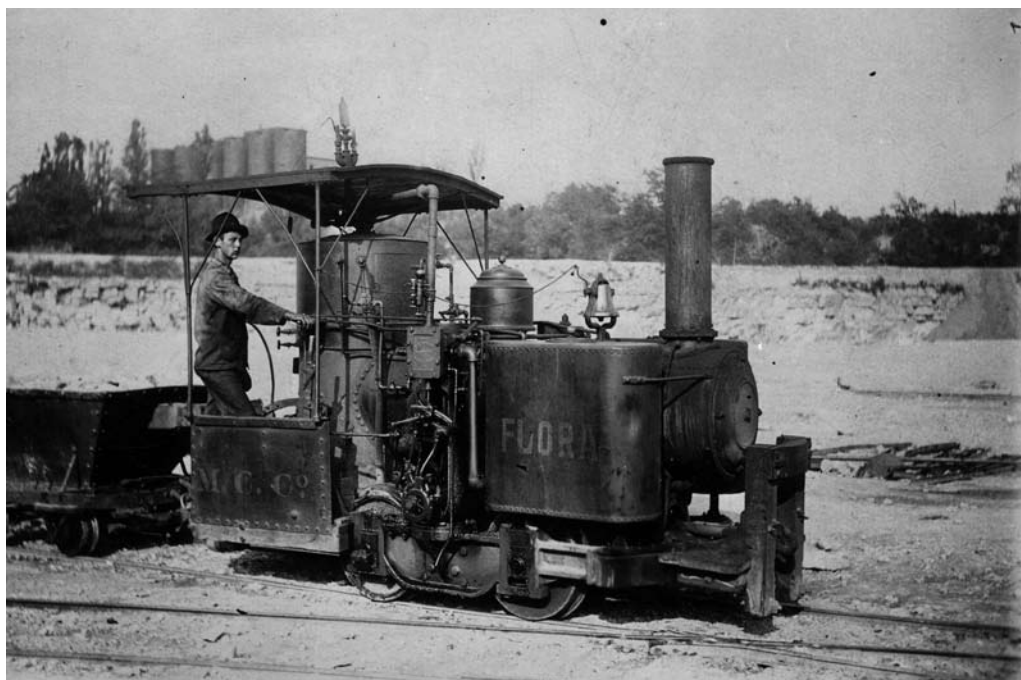


Fig. 345. Steam engine used to pull dump cars filled with cement rock from the quarry working face to the kilns in Mill # 2. Originally horses had been used to pull dump cars on the tramway in the Mill # 1 quarry; however, when this photograph was taken, sometime after 1887, steam power had replaced horses. This is a small example of the modernization regularly undertaken by the Milwaukee Cement Company at its operations. Courtesy of Historic Photo Collection / Milwaukee Public Library.

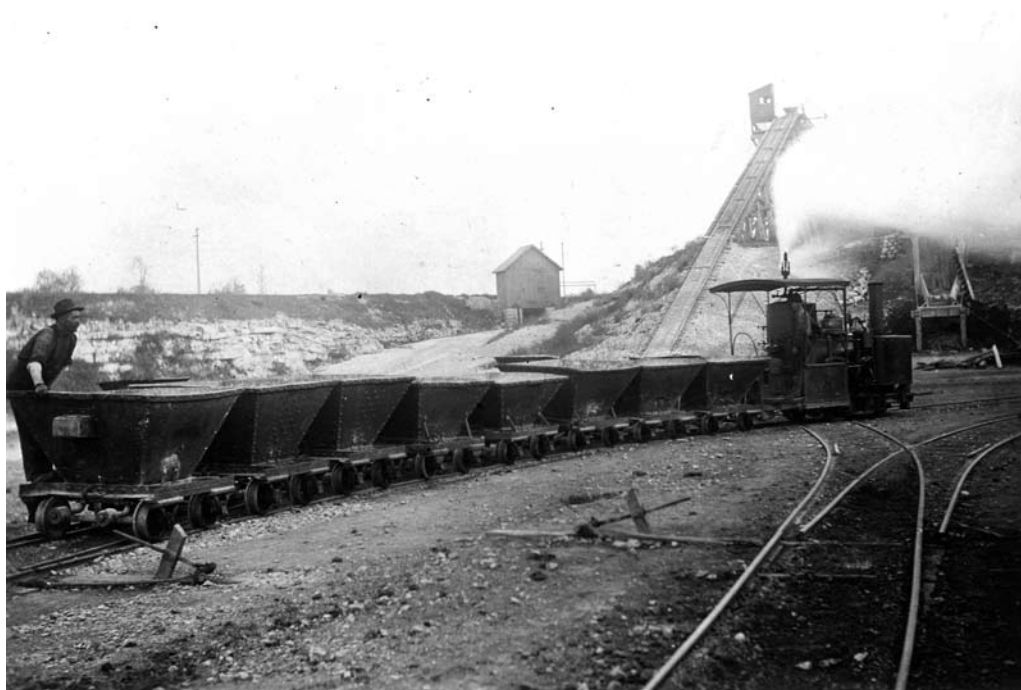


Fig. 346. Stone dump cars and steam engine used to transport cement rock to the kilns in the Mill # 2 quarry sometime after 1887. Courtesy of Historic Photo Collection / Milwaukee Public Library.



Fig. 347. Portion of map of Milwaukee Cement Company's property showing area around Mill # 1 + Mill # 2. This map was probably made after 1894 by R.R. Reinertsen as the surveyor. The 3 acre parcel located east of Mill # 1 and north of Milwaukee River near center of map is the former location of Cream City Cement Company plant. Used with permission of Wisconsin Historical Society and University of Wisconsin-Milwaukee Archives, 00001-scan_2019-01-25_08-37-30; detail of full map.

light in the mine was supplied by kerosene torches and the floor was always wet and pumps were working night and day. Pillars were left to hold up the ceiling which was also shored up by timbers. The Cream City Cement Company operated for only a few years but was "a serious competitor of the Milwaukee Company by their policy of cutting prices and selling below their cost. This ultimately proved to be a ruinous policy" (Berthelet, 1942). In 1894, the company and its land was purchased by the Milwaukee Cement Company more likely to eliminate a competitor than to gain its reserves of cement rock and its "plant was wrecked and tunnels abandoned" (Greene & Berthelet, 1949).

The only other significant cement rock exposures in the Milwaukee area were at Whitefish Bay and located at the base of a steep bluff along the Lake Michigan shore. Although probably known since the 1670s, the site could not be easily accessed for any type of stone quarrying as the rock bottom of the lake at this point made the water too shallow (18 to 24 inches) to approach by boat for commercial shipping. With no way to ship cement on the lake and no room for kilns or a plant along the shore, quarried rock had to be transported up to the top of the steep 100 foot high bluff where the plant and kilns were eventually built adding to production costs. Lapham (1844, unpublished manuscript) commented, "The clay bank above the rock is so steep that the fisherman stationed here are obliged to use a ladder for a part of the ascent". However, the potential profitability for investors to open a new cement operation at Whitefish Bay was too great to ignore. On September 1, 1892, the Milwaukee Brick and Cement Company was incorporated by Milwaukee investors to manufacture hydraulic cement, mud and pressed brick, sewer pipes, and tiles on their 143-acre site along the Lake Michigan shore (Anonymous, 1892). In January, 1893, a description of the Whitefish Bay cement plant was published (Baxter, 1893), with an illustration (Fig. 350) of the planned operations. The plant was to be built at the top of the bluff and would be connected by an incline to a quarry in the lake bed. Cement rock would be quarried from the lake bed where a water tight dyke was to be built surrounding a large area of the bedrock surface extending 1000 feet out from the shore. This basin would be pumped out and then stone could be quarried from the former lake bed. It was proposed that shipping of both brick and cement would be by rail at the top of the bluff and possibly by boat following the construction of piers and docks on the lake. A brick plant was built in 1893 on the top of the bluff and for a number of years brick was produced from clay excavated there. However, because of the complexity and cost of excavating cement rock at the lake level and hauling it up to kilns and a mill at the top of the bluff, the start of this part of the business was postponed for many years. Another possible factor in this delay was the financial Panic of 1893 which resulted in a serious economic downturn that lasted for several years. In 1899 construction was finally started on the cement plant, and in 1900 the company name was changed to the Consolidated Cement Company of Milwaukee with a renewed effort to enter the cement business. As previously planned, the kilns and a mill were built at the top of the bluff, however the plan to dyke off a quarry in the lake bed was abandoned and underground mining at the lake shore was started instead, presumably as a less complicated and expensive approach. Alden (1906, 1918) described the operations here as:

"Near this point, the Consolidated Cement Company has opened a shaft to supply its mill upon the bluff above. This shaft extends to a depth of 22 feet below the level of the beach, where it connects with a main gallery which, at the time of the writer's visit, extended 210 feet in a north-south direction. From this gallery drifts were being extended to the west in the working beds. The upper 5 or 6 feet is left as roofing and is not well exposed to examination, but material thrown out in excavating the shaft through these showed them to be of moderately hard, fine-grained, bluish-gray hydraulic limestone, characterized by an abundance of pyritized fossils, crystals of pyrite and of calcite, and traces of bitumen. The working face, which has a maximum height of 14 feet, shows dense, bluish-gray, massive to heavy-bedded magnesian limestone, having the same general appearance as that at the quarries on the river, but less distinctly marked bedding planes. So far as could be seen this part seems to be less fossiliferous than the beds composing the roof and those exposed along the river. The bedding is slightly undulatory, so that, though the general dip of the formation is toward the southeast, there is a slight dip to the west in the northern part of the exposure."

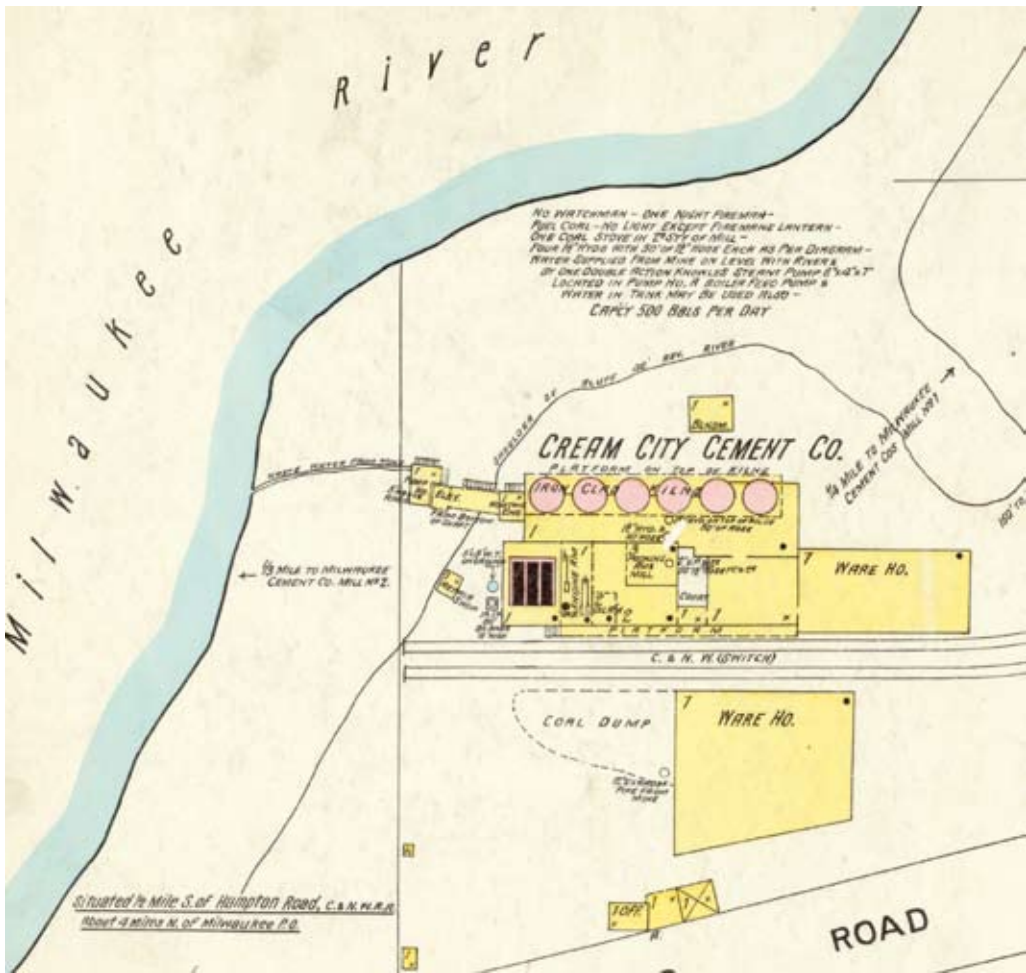


Fig. 348. Fire insurance map of the Cream City Cement Company showing the layout of the plant and the primary materials used in the construction of buildings and other structures. From; Insurance Maps of Milwaukee, Wisconsin, Volume Four, 1894, Sanborn-Perris Map Company, p. 459. Pink color indicates buildings primarily of brick construction, and yellow wood construction. From the American Geographical Society Library, University of Wisconsin-Milwaukee Libraries.

The roof rock was likely to be the same thick beds of Cleland's B zone and Raasch's Berthelet member which was also used for roof rock in the mines along the Milwaukee River. The cement operations of the Consolidated Cement Company were short lived. By 1904 the owners were asking for relief in their property taxes and in 1906 the company was no longer listed on local tax rolls (Nelson & Roberts, 1963), suggesting operations had ceased. In 1905, the operations were offered for sale in trade journals (Fig. 351).

Cleland (1911) stated that no work was being done at the mine when he visited the site in 1907.

Although a significant investment had been made to build a plant and kilns, construct a haulage system to bring cement rock to the top of the bluff, and develop a mine on the lake shore, the entire project was probably at the wrong place and certainly at the wrong time. The geologic conditions of the site limited the source of cement rock to underground mining at the lake shore, while also limiting the site of a plant and kilns to the bluff top where a transportation connection for rail shipping could be used. These complications by themselves would have made it difficult to manufacture cement as cheaply as was being done at the Milwaukee River locations of the Milwaukee Cement Company. However, the economic downturn resulting



Fig. 349. Right side of panoramic view in figure Fig. 342, showing the Cream City Cement Company plant with its mine shaft elevator on the right and the Milwaukee Cement Company Mill #1 quarry to the left. This view is from east side of Milwaukee River looking west. The development of the Milwaukee Cement Company Mill #2 (started 1887) and the presence of the Cream City Cement plant (demolished after 1894) suggests that the date the photograph was taken was in the early 1890s. Courtesy of Historic Photo Collection / Milwaukee Public Library.

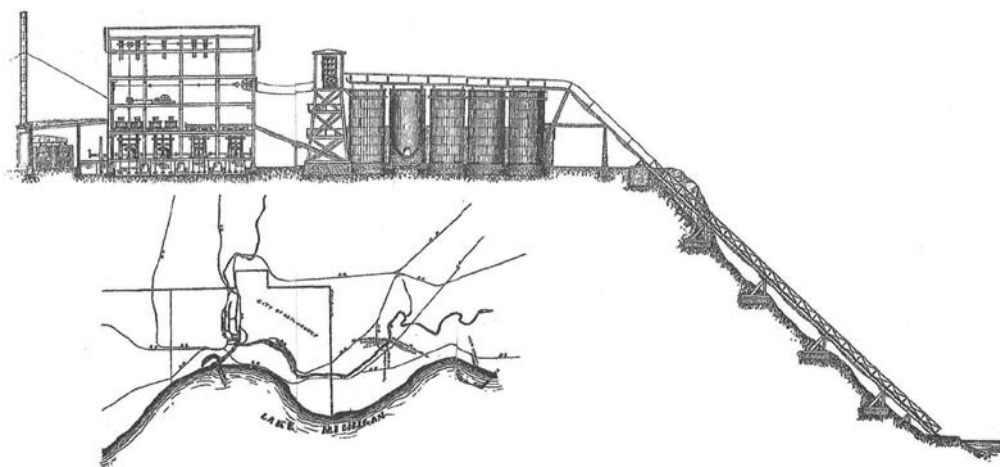


Fig. 350. Diagram showing the 1893 design of the Milwaukee Brick and Cement Plant to be built at Whitefish Bay. When the plant was finally built in 1899 under the name of the Consolidated Cement Company, the idea of quarrying cement rock in the lake bed had been changed to underground mining. This would have resulted in some changes to this diagram, but the basic concept probably remained the same. From A.E. Baxter, 1893.

FOR SALE

The plant of the Consolidated Cement Co., Milwaukee, with 75 acres of land on the Lake Shore and C. & N. W. Ry. Co., including Boarding House, cottages, etc.; best quality of Hydraulic Cement, Electric Conveyor for Lake Sand, Gravel; unsurpassed facilities for manufacturing Cement and Sand Brick, Concrete Blocks and Sewer Pipe. Plant modern, in full operation with established trade. Reason for selling: age of owner. Price low and with easy terms. Apply to
CHAS. L. KIEWERT, Milwaukee, Wis.

Fig. 351. Advertisement for sale of the Consolidated Cement Company in the July, 1905 issue of *The Cement Age*.

from the Panic of 1893 probably also had a role in delaying the development of the site, and reducing potential sales. This was followed by the rather abrupt collapse of the natural cement industry in general as Portland cement started to dominate the market ending any potential for further natural cement production the Milwaukee area. The Milwaukee Journal in a 1960s article stated that the mine shaft here was filled in 1929 although the partially water filled tunnels were left open. In recent decades when the surface level of Lake Michigan water was at its lowest, remnants of various cement manufacturing structures and equipment can still be seen along the lake shore (Lohr, 1964), but no other indications of the cement industry at this site are visible.

It is unlikely that either the Cream City Cement Company or the Consolidated Cement Company mines had any significant role in geologic research on the Milwaukee Formation or in supplying fossils for scientists and collectors. The natural lake shore exposures near the Consolidated Cement Company mine site have long been a somewhat less productive collecting site when compared with those at the large Milwaukee River quarries and have been partially covered by erosion protection structures in recent years.

The End of the Industry

The Milwaukee Cement Company had a rapid growth and an even more rapid decline. Despite having an excellent source rock for manufacturing natural cement, operating modern and innovative plants, and had an extensive sales network covering most of the central United States, the company, which was one of the dominant cement producers in the country, was powerless to stop its own collapse. Howard Greene and William Berthelet, who were prominent in the Milwaukee Cement Company, described (1949) the collapse as follows:

“Just when the company was at the height of its activity something occurred that sounded the death knell of the natural cement industry. The rotary kiln was invented. Through its use, what is known as Portland cement could be produced at low costs from various types of materials. Portland cement develops its early strength much sooner than natural cement, and also withstands climatic conditions much better.”

This change from natural cement to Portland cement was even more dramatic than it sounds. In the 1890s and 1900s the demand for and production of cement skyrocketed (Fig. 335). Part of this expansion resulted from new uses of cement in general, as Portland cement could be used in applications that natural cement wasn't well suited for or had previously existed. Portland cement for example replaced much of the use of lime mortars as a cementing agent. But more importantly was the major change in the types of building materials used in construction that occurred at the time. Cement used in concrete had begun to supplant stone materials that had been used in construction for thousands of years. Poured concrete and concrete blocks replaced building stone as the primary materials used to erect large structures. In conjunction with internal steel support it became possible to build true skyscrapers. The superior qualities of Portland cement resulted in new and expanded uses of cement in general. The problem with natural cement wasn't that it couldn't be used for some of these purposes but it simply wasn't as good or as cheap in many cases. Important new uses for cement also began at a time when economic prosperity and population growth would require vast amounts of cement to develop the infrastructure of a growing society. The most important of these new uses was in the form of road pavements needed for the transportation revolution following the invention of motor vehicles.

But if Portland cement hadn't supplanted natural cement, the Milwaukee Cement Company would probably have continued as an important cement producer; however, through no fault of its own and with no way to prevent the change, this prominent Milwaukee business rapidly declined. This was all due to the character of its cement rock which for a while was the best anywhere but was then replaced by a “new” product that was better for making concrete road pavements and concrete blocks. To keep its business going during the early 1900s, the company tried selling Portland cement which allowed the manufacture of its natural cement to continue on a small scale (Greene & Berthelet, 1949), but all production was finally suspended

in 1911. A few of the other U.S. natural cement plants were able to continue low levels of production for a few more years, but the Milwaukee Cement Company was not one of them.

The Quarry Sites After the Close of the Industry

When the quarrying and mining of cement rock ended in 1911, the Milwaukee Cement Company owned about 350 acres along the Milwaukee River at the northern edge of Milwaukee (Greene & Berthelet, 1949). Although over the years many other quarries in southeastern Wisconsin had been temporarily closed for economic reasons but later reopened, the extensive property holdings of the Milwaukee Cement Company were permanently abandoned as a source of any type of construction stone. What for several decades had been some of Wisconsin's most valuable mineral resource land would see its value rapidly decline and the additional production of cement rock or other types of stone products would never occur at the site again. The reasons for this abandonment were due to both geological and technological factors. Geologically the dolomitic rock of the Devonian Milwaukee Formation made excellent natural cement but it could not be used in making Portland cement its replacement because of its fixed chemical composition along with its high magnesium content. While other quarries in the Silurian dolomite rocks of southeastern Wisconsin could be used to make lime, crushed stone, or building stone, Milwaukee cement rock contained too much clay to make lime, was too soft to use as crushed stone, and was too weak and thin or irregular bedded to produce good building stone. Although there were large areas of the quarries where all of the cement rock had already been excavated, digging deeper into the underlying Thiensville Dolomite wasn't an option because of its poor quality as a construction material.

After the production of cement was discontinued, the company's mills were leased to the Michigan Quartz Silica Company which ground quartz from a gold mine in Michigan to make wood filler, paint filler, and polishing abrasives (Berthelet, 1942; Hore, 1915). This company first used Mill # 1 in its grinding operations but it was destroyed in a fire in March 1910 and they then switched to Mill # 2 which also burned to the ground in September 1916. After both mills were destroyed the company wrecked the kilns and salvaged their iron and bricks ending any further use of the plants. The stone ruins of the base of the kilns at plant # 1 could still be seen into the 1930s (Toepfer, 1977) but they were apparently buried. If these kiln foundations are still there they would be an important candidate for an industrial archeological study and preservation.

With the mills and kilns destroyed and no prospects of ever producing cement at the site again, the company began to sell its land around World War I. The City of Milwaukee was expanding north and the property had considerable value in providing new locations for industrial development. In addition, there was also a strong interest in preserving much of the land as parkland. The abandoned quarries had become mostly water filled and the manmade rugged topography of quarry cliffs and artificial lakes provided a unique and scenic landscape. Boating, fishing, hiking, picnicking, swimming and even fossil collecting (Mikulic & Kluessendorf, 2001), became popular activities along the river even though much of the land was never publicly owned. Some of the quarry area also attracted interest as sites for municipal garbage dumps. With these conflicting interests, the land was sold piecemeal until the 1940s and its ultimate use would long be controversial. The first important sale was made in 1916 when most of the land on the east side of the Milwaukee River was purchased by the new Milwaukee County Park system to create Estabrook Park. While the east side of the river became parkland however, the west side including the water filled Mill # 2 quarry, then known as Cement Lake, did not. In 1924, the City of Milwaukee bought much of the Mill # 2 quarry area to use as a dumping site for garbage. This started a controversy concerning the land use of this area which lasted decades and has still not been completely resolved. Specifically, the use of the west side property for dumping was in direct conflict with the plans of various groups that had interest in developing park land on both sides of the river including the Cement Lake area. In addition, using Cement Lake as a major dumpsite had a significantly negative impact on the public use of Estabrook Park as it was located directly across the river from the park spoiling its viewscape and adjacent river use. Other problems resulted from the dumping such as smoldering dump fires (Henkel, 1939), and trash floating down river plagued adjacent neighborhoods.

By 1929 there was considerable opposition from local citizens to continued filling of Cement Lake with garbage. Charles Whitnall, the architect of the Milwaukee County Park System and its urban greenways (Platt, 2010), long a proponent of the creation of river parkways, had become one of the leaders of this opposition. The City of Milwaukee really wanted dump sites but also claimed “safety” as a primary reason to fill Cement Lake. The vertical old quarry walls, the twenty to thirty-foot water depth, along with the open entrances to the partially flooded mines all made the area dangerous and it became notorious for drownings (Henkel, 1939). Many of these drownings resulted from the presence of submerged drop-offs into deeper water which were typical for many abandoned quarries. More unique to the site however was the partially flooded mines. In the summer, it was possible to enter some mines by boat, while during the winter when the flooded quarries were frozen over, some of the mine ceilings were high enough for people to walk into them; however, the ice rapidly thinned back into the darkness where there was open water all year long (Mikulic & Kluessendorf, 2001). Because of the drownings, by the late 1920s there was public pressure to make the area safe. Plans were made to fence off mine entrances, although they ultimately seem to have been just buried under fill. The opponents to dumping pointed out that most of the mine related drownings were not occurring at Cement Lake but in other “Blue Hole” areas. Even geologists expressed their opposition to dumping because it would bury the unique exposures of fossiliferous Devonian rocks.

In 1930, following opposition to the complete filling of the lake, a plan was agreed upon to landscape what remained of the Cement Lake area into park land, filling it to a shallow depth for safety, and create an adjacent west side parkway. This would have preserved some of the rock exposures in the area which contributed to its unique scenic beauty (Henkel, 1939). While this plan seemed to resolve many of the preservation issues, dumping continued at Cement Lake. In addition, further changes to the landscape occurred during the 1930s when a large and mostly undisturbed section of the river was dramatically altered by rechanneling both in Lincoln Park and adjacent Estabrook Park (Ziemke, 1935). Much of this work was done as part of WPA projects, which included the construction of the Estabrook Park dam. The river rechanneling had some scientific interest as it involved extensive rock excavations of both the lowest beds of the Milwaukee Formation and the upper Thiensville formation, both of which were seldom exposed.

Despite this temporary reprieve, Charles Whitnall died in 1949 and by 1952 the city had gone back to using the “preserved” part of Cement Lake as a garbage dump and burn site. Despite continuing public protests, the entire area was eventually buried under trash, eliminating all indications of what was once a prominent industry along the west side of the river except for small areas near the railroad bridge. Despite promises from as far back as the 1920s, the Cement Lake site has not yet become a park site and since the 1970s has been a parking lot for the University of Wisconsin-Milwaukee. With decades of garbage dumping and park landscaping, nearly all of the formerly extensive rock exposures in outcrops and quarry walls have been obliterated. Several studies (Mikulic & Kluessendorf, 1982, 1997) have proposed preserving some of the very few remaining exposures of the Devonian rocks along the river but little has been accomplished to date. What had once been a grand window into the geologic history of Milwaukee and Wisconsin, a demonstration of the importance of mineral resources in building a major Midwestern urban area, while also providing a scenic and unique recreational site for the community, has almost completely disappeared, never to return. Estabrook Park is now a nicely landscaped park. Few would ever know that the conspicuous falls on the river are the manmade remnants of a once great industry.

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Glossary

Abaxial—Directed away from the longitudinal axis of an organism or structure.

Acanthodii—The class of teleosts having dermal and perichondral bone as well as a series of stout spines before its dorsal, anal and paired fins. This class was, for a short time, included within the Placodermi, but is now recognized to have more features in common with the Osteichthyes.

Actinoceratoidea—The subclass of cephalopods having shells of medium to large size ranging in shape from straight and slender to slightly curved, simple, curved septa and sutures, and typically a siphuncle that was broadly expanded between septa and at least partially filled with calcareous deposits.

Abaxial—Directed toward the longitudinal axis of an organism or structure.

Ambulacrum (pl. a)—Structure in echinoderms (generally five or multiples of five in number) in which food is conveyed to the mouth.

Ammonoidea—An extinct subclass of marine cephalopods bearing an external, chambered shell divided by partitions (septa) that have convoluted margins which are often sufficiently distinct to aid in identification of species.

Amphibian—Member of the Amphibia, a class of cold-blooded vertebrates having gilled aquatic larvae and air-breathing adults; includes frogs, toads, salamanders and newts.

Animalia (=Metazoa)—The kingdom of multicellular eukaryotes that typically feed on organic matter, process it in a central cavity, and are mobile for at least part of their lives.

Annelida—The protostome animal phylum of aquatic or terrestrial, vermiform, bilaterally symmetrical, coelomate metazoans that have a segmented external cuticle that is never molted; includes earthworms, leeches, marine worms and many other worm-like animals.

Anthozoa—A class of aquatic (mostly marine) polypoid cnidarians having a tubular body, tentacles around their mouths and generally sedentary adults. Unlike the other cnidarian classes, they do not have a medusa stage in their development. Includes corals, sea anemones, and sea fans.

Antrim Shale—An Upper Devonian formation lying unconformably on the Milwaukee Formation; known in Wisconsin only from glacial erratic blocks, float from tunnel excavations, and core samples; the Wisconsin material is the western-most occurrence of the Antrim Shale, which is found more extensively in Ohio, Indiana and the type locality, eastern Michigan.

Apatite—A group of calcium phosphate minerals whose members are major constituents of bones, teeth and certain shells and other skeletal materials of such invertebrates as lingulid brachiopods and the extinct conodonts and conulariids.

Aragonite—An unstable morph of calcium carbonate, generally having a pearly luster, found primarily in certain layers of the shells of brachiopods and mollusks; transforms into calcite over time.

Arborescent—Tree-like in form and size.

Archaeobacteria (=Archaea)—The domain of single celled organisms that are essentially intermediate between the two other domains, Eubacteria and Eucaryota; includes forms that can live in extreme conditions such as hydrothermal vents, hot springs, and hypersaline water.

Argillaceous—Pertaining to rocks composed of grains less than 0.0625 mm in diameter, i.e., clay rich.

Arthropoda—The protostome animal phylum having a chitinous exoskeleton and typically segmented body with jointed legs; includes the chelicerates, trilobites, myriapods, crustaceans, insects, and many other living and extinct aquatic and terrestrial groups; the most diverse phylum of animals.

Articulated—Hinged or otherwise held together, generally via interlocking parts.

Asphaltum—A black, tar-like substance occurring in rock cavities and derived from life forms through natural processes.

Astrozoa—A more-or-less star-shaped class of echinoderms typically having five (or multiples of five) appendages, each with a series of tube feet (hydraulically operated by a water vascular system) on either side of the ambulacra; includes sea stars (starfish) and brittle stars.

Benthic—The marine zone including the region on or beneath the sea floor.

Berthelet Member—The lowest (oldest) member of the Milwaukee Formation, overlying the Thiensville Formation and underlying the Lindworm Member; comprised of medium to thick bedded argillaceous limestone and argillaceous dolomite; fossils generally in the form of internal and external molds; the source of most of the Milwaukee Formation's fossil fish and land plants.

Biocalcarene—A detrital carbonate rock composed of sand-sized particles largely derived from animal and/or protist shells.

Biota—The animals, plants, fungi and other life forms of a particular place, time, environment, or geological unit.

Bioturbation—The restructuring of sedimentary deposits by moving organisms.

Bivalvia—The class of aquatic mollusks that includes the clams, oysters, mussels and related forms typically possessing two calcareous shells that hinge together and enclose a muscular foot and other soft parts.

Blastoidea—An extinct class of echinoderms with biserial brachioles bordering their ambulacral areas, well developed pentameral symmetry, seventeen major plates (basals, radials and deltoids) arranged in three circlets, a lancet plate underlying its ambulacral system, an anus, mouth, hydrospires on either side of each ambulacrum crossing the plate suture, and typically a spiracle near the adoral extremity of each ambulacrum.

Blastopore—The first opening formed in the central cavity of an embryo during gastrulation.

Brachial valve (=dorsal valve)—Valve that invariably contains any skeletal support for lophophore and never wholly accommodates pedicle; commonly smaller than ventral valve and with distinctive muscle-scar pattern.

Brachidium (pl. a)—One of the pair of calcareous supports for the lophophore of brachiopods, in the form of a loop or spire.

Brachium (pl. a) (=arm)—In certain crinozoans (e.g., crinoids), one of the food-gathering appendages attached to the top of the calyx.

Brachiole—In blastoids, one of the slender food-gathering appendages attached to the lancet plates at the border of the ambulacra.

Brachiopoda—The lophophorate animal phylum consisting of solitary, marine, sessile, coelomate, metazoans having a pair of calcareous or chitinous valves that are bilaterally symmetrical about the median plane that is normal to the surface of separation between valves.

Breccia—Sedimentary rock composed primarily of large, angular or subangular fragments cemented by a matrix of smaller particles that may be of a different composition.

Bryozoa—The lophophorate animal phylum consisting of colonial, aquatic, generally sessile, polymorphic metazoans, regarded as coelomate, with a retractable food-gathering lophophore, U-shaped digestive tract and typically having a calcareous skeleton.

Calcareous—Composed largely or entirely of at least one morph of calcium carbonate.

Calcining—The heating of solids to a high temperature for the purpose of removing volatile substances, oxidizing a portion of mass, or rendering them friable.

Calcite—The most common morph of calcium carbonate; the primary mineral of which limestone and many calcareous shells are made.

Calyx (=Cup) (Zoological context)—The head region of a crinozoan exclusive of its brachia/brachioles, enclosing the main portion of the visceral mass.

Cambrian—The first period in the Paleozoic Era, ranging from about 541,000,000 to 485,000,000 years ago, from which the oldest abundant fossils are encountered; followed by the Ordovician Period.

Carboniferous—The period in the Paleozoic Era between the Devonian and Permian Periods, ranging from about 359,000,000 to 299,000,000 years ago.

Carina (pl. ae)—In conulariids, an internal, thickened ridge located along the corners and/or midlines of the periderm.

Caustic potash—Potassium hydroxide (KOH); a strong alkali once used to remove calcareous matrix from fossils; generally fallen into disuse due to its health hazards and destructive effects on the fossils themselves.

Cenozoic—The era following the Mesozoic Era, including the Paleogene, Neogene and Quaternary periods; last 65 million years of Earth history.

Cephalon (pl. a) (Zoological context)—The head region of certain arthropods, e.g., trilobites.

Cephalopoda—The class of agile, bilaterally symmetrical, predacious molluscan carnivores typically having a pair of complex eyes, a beak, a set of eight or more elongated, flexible appendages, and a funnel for propulsion through the water; have either a single calcareous external or internal shell or may lack a shell entirely.

Chaetognatha (=Arrow worm)—The phylum of planktonic and nektonic, coelomate, bilaterally symmetrical, mostly marine and predatory, wormlike animals.

Chert—An opaque sedimentary rock composed of extremely fine-grained crystals of silica.

Chimaeroidei—The chondrichthyan suborder that typically has grinding tooth plates and a prominent leading spine on the first dorsal fin; includes the ratfish.

Chitin (Biochemical context)—A stiffening yet flexible nitrogenous material of which fingernails, hooves and many invertebrate exoskeletons (especially arthropods) are primarily composed.

Chitinophosphatic—Composed of chitin and phosphates (especially calcium phosphate), such as the outer covering of conulariids and the shell of lingulid brachiopods.

Chitinozoan—Enigmatic, flask-shaped marine microorganisms or egg cases (Ordovician–Holocene) typically composed of chitin-like material.

Chondrichthyes—The class of gnathostomes having cartilaginous endoskeletons—the males having a pair of claspers; includes the sharks, rays, chimaeras, and related forms.

Chordata—The phylum of bilaterally symmetrical animals having a notochord and pharyngeal gill slits in adults or certain embryological stages; includes the urochordates (tunicates), cephalochordates (lancelets), craniates, and, tentatively, conodonts.

Claspers—The paired organs of the male of certain animals, such as chondrichthyans and certain placoderms, used for stabilization during mating.

Class—The rank in taxonomic hierarchy between phylum and order.

Cnidaria—The phylum of acoelomate, headless, aquatic, predatory, colonial or solitary, polypoid or medusoid animals having a mouth surrounded by stinging-cell-bearing tentacles; includes corals, sea fans, hydroids, and jellyfish.

Coelacanthiformes—The sarcopterygian order that includes the extant *Latimeria*, classically labeled a "living fossil."

Coelom—A fluid-filled body cavity lined with mesodermal cells; found in vertebrates and many other bilaterally symmetrical animals.

Coleoidea—The subclass of cephalopods that includes most of the living forms, such as octopi, squids, and cuttlefish; typically shellless, but often with a hard internal structure, such as a gladius (in many squids), cuttlebone (in cuttlefish) or thickened rostrum (in the extinct belemnoids).

Column—In most stalked echinoderms, an elongated cylindrical structure on the aboral end of the calyx with which it attaches to the substrate at its other extremity; sometimes referred to as a stalk.

Columnal—The unit ossicle composing the crinozoan column; typically discoidal in shape.

Commensalism—A relationship between individuals of two species (A and B) in which A benefits from B without either harming or benefiting B.

Commensal—The species that benefits from the commensalistic relationship.

Conodonta—The class of small, marine, pelagic and benthic chordates of eel-like form having head regions containing assemblages of microscopic phosphatic tooth-like structures also termed conodonts.

Conulariida—The extinct group of sessile benthic, polypoid scyphozoan cnidarians having a steeply pyramidal, generally four-sided periderm constructed of alternating, extremely thin organic and apatitic lamellae that in some species could be folded to cover the oral end of the animal.

Corallite—The exoskeleton of a solitary polyp or of a bud in a colony of anthozoans.

Craniata—The chordate subphylum characterized by possession of a cranium.

Cranidium—In trilobites, the central portion of the exoskeleton of the cephalon bounded laterally by the facial suture.

Cretaceous—A period in the Mesozoic Era between the Jurassic and Tertiary, ranging from about 145,000,000 to 66,000,000 years ago.

Crinoid—Member of the Crinoidea, a class of stalked echinoderms with pentamerous symmetry and five (or multiples of five) outspread, branched, food-gathering arms (brachia).

Crinozoa—The subphylum of echinoderms typically attached by a stalk and possessing a calyx having ambulacra that served as food grooves extending outward onto projecting appendages (brachia or brachioles).

Crustacea—The subphylum of mandibulate arthropods typically having two pairs of pre-oral appendages; includes crabs, lobsters, isopods (wood lice), amphipods, copepods, ostracods and other living and extinct forms.

Ctenophora—The phylum of carnivorous, marine, generally free swimming animals placed until recently in the same phylum with the Cnidarians; unlike cnidarians, ctenophores lack stinging cells and bear few to no tentacles, having instead a series of ciliated combs for locomotion and a sticky substance for capturing prey; comb jellies.

Cyanobacteria (=Blue green “algae”)—The phylum of photosynthetic eubacteria accounting for much Earth’s oxygen; some types can form multicellular colonies of biofilms, biomats or stromatolites, in some cases working in symbiosis or metabolic cooperation with algae and other types of organisms.

Dendroidea—The order of sessile graptolites attached by the apex of the sicula, which is then generally more or less embedded in secondary cortical tissue forming a root-like base.

Dermal plate—One of the bony plates hinged or joined together in the head and thoracic regions of placoderm fishes forming a body armor either on the surface or beneath a layer of skin.

Deuterostomia—The subkingdom of animals having a mouth that develops from a secondary opening in the embryonic gut other than the blastopore; includes the Bryozoa, Brachiopods, Chaetognatha, Echinodermata, Hemichordata, and Chordata, and several minor phyla.

Detritus—Loose material, such as rock fragments or organic particles, that results directly from disintegration rather than from crystallization or other means.

Detrivore—One who feeds on detritus.

Devonian—The period in the Paleozoic Era between the Silurian and Carboniferous Periods, ranging from about 419,000,000 to 359,000,000 years ago; the period in which the Milwaukee Formation was deposited.

Disarticulated—Unhinged or otherwise disjoined.

Disconformity—An unconformity such that the beds above and below the surface are parallel.

Dissolution (Geological context)—The breakdown of a material into individual ions, atoms or molecules by water or other solvents.

Dolomite—The mineral calcium magnesium carbonate, generally including lesser amounts of iron in place of the calcium and magnesium.

Dolomitization—The process by which limestone (calcium carbonate) transforms to dolomite via replacement of some of the calcium ions by magnesium ions.

Domain—Generally regarded as the highest rank in taxonomic hierarchy, positioned immediately above kingdom.

Dorsal valve (=brachial valve)—Valve that invariably contains any skeletal support for lophophore and never wholly accommodates pedicle; commonly smaller than ventral valve and with distinctive muscle-scar pattern.

Doublure—In trilobites, the reflexed continuation of the dorsal exoskeleton onto the ventral surface.

Dysaerobic—Pertaining to a depositional environment having 0.1 to 1.0 ml of dissolved oxygen per liter of water.

Echinodermata—The deuterostome animal phylum of coelomate, marine, benthic (exceptionally pelagic) metazoans lacking a differentiated head or brain and typically having pentamerous symmetry, an endoskeleton formed of plates and other distinct ossicles composed of crystalline calcite, and a water vascular system; includes the familiar starfish and brittle stars (Asterozoa), sea urchins, sand dollars, and sea cucumbers (Echinozoa), sea lilies and related forms (Crinozoa), and lesser known living and extinct subphyla.

Echinozoa—The subphylum of echinoderms with radial symmetry, meridional pattern of growth producing an essentially globoid body, but no projecting appendages.

Ediacaran—The last period of the Neoproterozoic Era, ranging from about 635,000,000 to 543,000,000 years ago, followed by the Cambrian Period.

Edrioasteroidea—The class of sedentary, stalkless, radiate echinozoans that had a domal, clavate, or globose polyplated theca; ambulacra (generally five) endothecal, formed by floor plates and cover plates.

Embryophyta—The group of photosynthetic plants distinguished from the other plants by producing embryos that it nurtures within its body; includes mosses and all other land plants.

Endochondral bone—Cellular bone that develops by replacing cartilage with bone; typically found in the long bones of the skeleton.

Endoskeleton—A skeleton located within the body of certain organisms such as vertebrates, echinoderms, and various mollusks, for the purpose of muscle attachment, protection of internal organs, or both.

Epibiont—An organism that lives on and generally attaches to another organism.

Epifauna—Benthic fauna living on the substrate or on other organisms.

Eubacteria—Prokaryotic organisms having a simple RNA structure and specific cell wall chemistry.

Eucaryota—The domain of organisms that contains cell nuclei and organelles; includes all organisms except eubacteria and archaeobacteria.

Euthycarcinoid—The enigmatic, mandibulate arthropod having a segmented tail region and up to twenty-eight pairs of undifferentiated walking legs; Middle Cambrian to Triassic.

Evaporitic—Pertaining to deposits of minerals precipitated when evaporation in a body of water exceeds the rate of introduction of additional water.

Exoskeleton—A stiffened external protective and supportive covering on certain animals, especially invertebrates.

External mold—Sediment that surrounds the outside surface of a shell or skeleton, that shows an impression of the outside of the shell or skeleton, often showing external shell structures such as growth lines and ornamentation.

Facial suture—In trilobites, the suture bounding the adaxial margin of the eye surface; has anterior and posterior branches, each of which may extend over the border and onto the doublure; separates free cheek from fixed cheek.

Family—The rank in taxonomic hierarchy between order and genus.

Fenestrate—In bryozoans, a growth habit modification in which slender branches separated by rectangular open spaces called fenestrules are arranged in a reticulate pattern to form broad fronds.

Fixed cheek (=Fixigena)—In trilobites, the portion of the cranium abaxial to the axial and prelabellar furrows and imaginary sagittal line bisecting the frontal area.

Foraminiferida—The phylum of amoeboid, unicellular protists that are generally microscopic, marine and include a chambered shell with foramen (perforations).

Free cheek (=Librigena)—In trilobites, the portion of the cephalon abaxial to the facial suture.

Fucoid—A member of or resembling the algae *Fucus*.

Fungus—The kingdom of single or multi-celled eucaryotes that typically have a system of filaments and spores; includes such organisms as mushrooms, yeasts, and molds; considered more similar to animals than to plants.

Funnel—See hyponome.

Gastropoda—A diverse class of vagile aquatic or terrestrial mollusks, including snails and slugs, that typically have a spiral calcareous

shell, although some shells are conical, cap-shaped or absent.

Genus—The rank in taxonomic hierarchy between family and species.

Geode—A cavity in a rock or fossil that has become lined with one or more layers of a mineral, generally silica or calcite.

Glabella—The central portion of the cranidium of a trilobite.

Gnathostomata—The superclass of craniates that have jaws; the jaws are derived from modified gill arches; this group includes the classes Placodermi, Chondrichthyes, and the grade Teleostomi, which in turn includes the classes Acanthodii and Osteichthyes.

Graptolithina—The class of sessile or pelagic colonial marine hemichordates that secreted a sclerotized exoskeleton with characteristic growth bands and growth lines; the thecae housing individual zooids were usually arranged in a single or double row along the branches (stipes) of the colony (rhabdosome); rhabdosomes originated by a single bud from the initial zooid, housed in a conical scula, producing simple, branched or rarely encrusting colonies.

Hemichordata—The deuterostome animal phylum generally having embryonic pharyngeal openings but lacking the endostyle and notochord distinctive of the chordates.

Hold-fast—The root-like or disc-shaped structure at the distal end of a crinozoan's column used to anchor the animal to the substrate.

Holocene—The current epoch; in the Quaternary Period, following the Pleistocene Epoch, ranging from about 11,700 years ago to the present.

Hydraulic cement—Cement that chemically reacts and hardens with water, and is capable of doing so under water.

Hydrospires—Thin-walled, folded structures within the calyx of blastoids believed to have aided in respiration.

Hydrozoa—The class of generally carnivorous, colonial cnidarians having a tubular body, a vellum that aids in swimming in medusae, tentacles around their mouths that lack stinging cells, and may have either a polypoid stage, medusa stage, or both. The skeletons of colonial forms are generally chitinous, but calcareous in some species.

Hyolithida—The extinct group of probable lophophorates whose calcareous fossils include bilaterally symmetrical, conoidal sclerites that are open at their wider ends, an operculum, and a pair of lateral spines.

Hyponome (=Funnel)—In cephalopods, the fleshy tube used to propel the animal by forcing water through it.

Hyponomic sinus—In nautiloid and ammonoid cephalopods, the indentation of the shell's aperture through which the hyponome extends outside of the living chamber.

Hypostome—In trilobites, a plate attached to the ventral side of the carapace beneath the glabella; believed to have been related to feeding.

Ichnogenus—A group of related ichnospecies.

Ichnospecies—The lowest rank in the hierarchy of trace fossil taxa.

Infaunal—Living within the sediment beneath a body of water.

Infraphylum—The rank in taxonomic hierarchy between subphylum and class.

Internal mold—Sediment filling the inside surface of a shell, often showing impressions of internal shell structures such as muscle scars.

Jurassic—The period in the Mesozoic Era between the Triassic and Cretaceous Periods, ranging from about 201,000,000 to 145,000,000 years ago.

Lake Church Formation—The Middle Devonian formation in southeastern Wisconsin that immediately underlies the Thiensville Formation and, depending on the exact location, overlies either the Waubakee Dolomite or Racine Dolomite.

Lancet plate—Elongate spear-shaped plate inserted between the deltoids of blastoids. The brachioles are attached to these plates.

Lindworm Member—The member of the Milwaukee Formation between the Berthelet and North Point Members; more thinly bedded and fossiliferous than the Berthelet Member.

Linguliformea—The subphylum of brachiopods having organophosphatic stratiform shells that are not articulated or with rudimentary articulation not involving teeth and sockets, and possessing a pedicle formed as an extension of the ventral body wall.

Lophophorate—A group of lophophore-bearing coelomate organisms that includes brachiopods, bryozoans, and phoronids.

Lophophore—A ciliated structure used by certain aquatic animals, such as brachiopods, bryozoans, phoronids, and hyoliths, to gather and transport food to the mouth.

Lycophytina—Tracheophytes having leaves arranged in a dense, regular spiral pattern that result in distinctive scar patterns in the deciduous members of the group; leaves are narrow and typically with one unbranched vein; some Middle Devonian through Carboniferous forms were arborescent; lycopods.

Keratinous—Composed of the fibrous protein, keratin; the main constituent of hair, feathers, nails, hooves, and horns.

Kingdom—The rank in taxonomic hierarchy between domain and phylum.

Lycopod (=lycophyte)—A member of the Lycophytina

Malacostraca—The class of crustaceans with a carapace of widely varied form typically covering all or most of the head and trunk regions; head typically bearing paired compound eyes commonly located at tips of movable eye stalks, with five pairs of appendages behind the eyes (antennules, antennae, mandibles, maxillules and maxillae); trunk composed of eight thoracic somites and six or seven abdominal somites, most equipped with paired appendages; includes crabs, lobsters, and crayfish.

Mandible—The chitinous chewing structure found in millipedes, crustaceans, insects and certain other living and extinct arthropods; also the lower jaw of vertebrates.

Marcasite—The morph of the mineral iron sulfide (FeS₂) in the orthorhombic crystal system and is tin white in color on freshly fractured surfaces, but quickly weathers to ferrous sulfide, which is crumbly and orange in color.

Medusoid—Having the mode of life, form, orientation of a medusa, thus being free-swimming, having an umbrella-shaped body, with a mouth and tentacles facing ventrally.

Membrane bone—Bone that forms in membranous tissues and not as a replacement of cartilage.

Meridional—Pertaining to a meridian, which is a line running from pole to pole of a rounded structure; describes the pattern of growth found in echinoids and holothurians (sea cucumbers).

Mesenteries—In anthozoans, the vertically-oriented sheet-like partitions that radiate inward from the body wall toward the central cavity of the polyp; the organs of digestion, adsorption and excretion, and the site of development of the gonads.

Mesozoic—The era immediately following the Paleozoic and preceding the Cenozoic Eras, beginning with the Triassic Period and continuing to the Cretaceous Period.

Metazoa—See Animalia.

Microconchida—The order of encrusting tentaculitoids having a small, spiral shell.

Millerite—The mineral nickel sulfide (NiS); metallic pale brass-yellow crystals frequently forming as radiating needles associated with calcite; sometimes secondarily altered on its surface to emerald green zarateite (hydrous nickel carbonate).

Millipede—A member of the myriapod class Diplopoda, which is typically characterized by possession of an elongated, cylindrical body and numerous pairs of legs distributed as two pairs per segment.

Milwaukee Cement Company—A large producer of hydraulic cement located at the northeast side of Milwaukee, Wisconsin, and operating between 1876 and 1909. The source rock was certain layers (primarily the Berthelet Member) of the Milwaukee Formation.

Milwaukee Formation—A Middle Devonian (Givetian) formation located in Milwaukee County, Wisconsin, and lying above the Middle Devonian Thiensville Formation and below the Upper Devonian Antrim Shale; contains a diverse biota of fossilized invertebrates, fish, and rare land plants; consists of three members, in ascending order: Berthelet, Lindwurm and North Point.

Mollusca—The protostome animal phylum consisting of aqueous and terrestrial, nonsegmented (except for the Polyplacophora) invertebrates having a fleshy mantle that secretes a calcareous shell of one or more pieces. The shell may be exteriorly-facing, enclosed by the mantle, reduced or lost; includes snails, clams, squids and related forms.

Monophyletic—A relationship among a group of organisms in which the group is descended from a common ancestor, and includes all of the descendant groups.

Monticule—In some bryozoans, a cluster of polymorphs which makes a prominence on the surface of the zoarium; a macula.

Natural reef—A large subaqueous moundlike structure composed of the skeletons of various organisms such as corals, bryozoans and/or other biota that secrete calcareous skeletal materials; typically includes the living producers of these materials and a diverse and prolific community of other species that also inhabit the reef. Although the Milwaukee formation contained bryozoans and corals, it lacked reef structure.

Nautiloidea—The subclass of cephalopods having small to large external shells ranging in shape from straight to tightly coiled, simple, curved septa and sutures, and lacking the close-packed endocones or complex annular deposits characteristic of some of the other subclasses.

Nekton—Animals that swim freely against currents.

Neogene—The period in the Cenozoic Era between the Paleogene and Quaternary Periods, ranging from about 23,000,000 to 2,600,000 years ago.

Neoproterozoic—The era preceding the Paleozoic Era.

Nitrogenous (Biological context)—Containing nitrogen, such as chitin, skin and many other biologically produced materials.

North Point Member—The youngest member of the Milwaukee Formation, lying above the Lindwurm Member and below the Upper Devonian Antrim Shale; lithologically similar to and apparently continuous with the Lindwurm Member, but contains many silicified fossils.

Notochord—One of the defining features of the Chordata, consisting of a rod-like flexible embryonic structure that persists in the adults of certain subphyla and contributes to the ossification of vertebrae in the vertebrates.

Operculum—The keratinaceous or calcareous plate attached to the foot of many gastropods for partial or complete closure of the aperture.

Order—The rank in taxonomic hierarchy between class and family.

Ordovician—The period in the Paleozoic Era between the Cambrian and Silurian Periods, ranging from about 485,000,000 to 444,000,000 years ago.

Ossicles—The discrete calcareous entities that comprise the exoskeleton of echinoderms or are embedded in their skin, providing support, protection and defense.

Osteichthyes—The class of gnathostomes having endochondral or membrane bone; skull with sutures; lung(s) usually present, functioning either as air-breathing organs or as buoyancy-controlling swimbladders or both; includes the Sarcopterygii and the Actinopterygii.

Ostracoda—The class of crustaceans that is aquatic, semi-microscopic, kidney bean-shaped, bi-valved, and mostly free-swimming.

Otoliths—Calcareous bodies within the inner ear of teleosts; play a critical role in the sense of balance.

Paleogene—The first period in the Cenozoic Era, between the Cretaceous and Neogene Periods, ranging from about 66,000,000 to 23,000,000 years ago.

Paleozoic—The era between the Neoproterozoic and Mesozoic Eras, beginning with the Cambrian Period and ending with the Permian Period.

Paraphyletic—A relationship among a group of organisms in which the group is descended from a common ancestor, but does not include all of the descendant groups; e.g., Pisces, which was defined to exclude the Tetrapoda, which is believed to have descended from the same common ancestor.

Pedicle—The fleshy organ of a brachiopod with which the animal typically attaches to the substrate.

Pedicle valve (=ventral valve)—Valve through which pedicle commonly emerges, usually larger than dorsal valve and invariably containing teeth when present.

Pedogenic—Pertaining to the formation and development of soils and related sediments.

Pelagic—The marine zone that includes the entire column of water above the benthic zone.

Perichondral bone—Bone that is typically thinly laminated, acellular, surrounds the soft tissues and is ossified from a layer of tissue that surrounds the cartilage as it develops.

Periderm—The thin, flexible organo-apatitic covering of a conulariid.

Permian—The last period in the Paleozoic Era, between the Carboniferous and Triassic Periods, ranging from about 300,000,000 to 250,000,000 years ago.

Permineralization—The fossilization process in which calcite or to a lesser extent silica or other dissolved minerals in the groundwater crystallize within the pores of skeletal remains.

Phanerozoic—The eon following the Precambrian, ranging from about 541,000,000 years ago to the present.

Phoronida—The phylum of solitary lophophorate metazoans having a long, flexible tube-like body.

Phyllocarida—The order of malacostracan crustaceans whose head and thoracic regions are encased in a bivalved chitinous carapace.

Phylum (pl. a)—The taxonomic rank typically lying between the rank of kingdom and class or subphylum.

Pinnules—Fine projections of certain crinoid arms that may be used as filters during feeding.

Pisces—The name of a subdivision of vertebrates previously used to include what were considered to be fishes and to exclude tetrapods; generally abandoned due to the paraphyletic nature of the group.

Placodermi—The class of marine and freshwater gnathostome (jawed) craniates having a mostly cartilaginous endoskeleton and bony dermal plates covering their head and trunk.

Plankton—Animals and plants that float or drift in a body of water, but are unable to swim against the currents.

Polychaeta—The diverse class of mostly marine annelids that typically bear unjointed appendages that develop as extensions of the animal's body segments.

Polypoid—Having the mode of life, form, orientation of a polyp, thus typically being attached at its base, with a mouth and tentacles facing dorsally.

Pleistocene—The first epoch of the Quaternary Period, between the Pliocene and Holocene Epochs, ranging from 2,580,000 to 11,700 years ago.

Polymorphic (Biological context)—Having more than one form within the same species, each generally having its own function; e.g., honey bees with their drone, worker, and queen morphs.

Precambrian—The eon prior to the Phanerozoic, beginning with the formation of Earth (about 4,600,000,000 years ago) and ending about 541,000,000 years ago.

Prokaryota—The domain of single-celled organisms that lack a nucleus and organelles.

Protista—The kingdom of eukaryotic organisms that are typically microscopic and single-celled or in the form of colonies of identical cells.

Protostomia—The subkingdom of animals having a mouth that develops from the first opening into the embryonic gut (blastopore); includes the Mollusca, Annelida and Arthropoda.

Ptyctodontiformes—The placoderm order characterized by its sturdy, blunt, frequently textured chewing surfaces presumably specialized for crushing shells.

Pygidium (pl. a)—In trilobites, the posterior portion of the exoskeleton separated from the thorax by articulation.

Pyrite—The morph of the mineral iron sulfide (FeS_2) that is in the cubic crystal system and metallic brassy yellow in color; weathers to limonite; "fool's gold."

Quaternary—The current geological period, following the Neogene Period, ranging from 2,580,000 years ago to the present.

Radiolaria—The phylum of protists bearing a siliceous test of varying shapes and intricate designs.

Radula—The keratinaceous, tongue-like structure in the mouth of most mollusks used for rasping food off a surface or drilling into shells.

Ramose—Branching, as in ramose corals or bryozoans.

Replacement (Paleontological context)—A type of fossil preservation in which groundwater-derived minerals entirely replace the skeletal materials of the organism.

Reptant—A growth habit of such colonial animals as certain corals and bryozoans, in which the colony is typically chainlike, branching and attached to the substrate by most or all of its habitation cells.

Rhabdosome—The sclerotized exoskeleton of an entire graptolite colony.

Rheophilic—Preferring or living in flowing water.

Rhombohedral cleavage—The tendency of minerals in the hexagonal crystal system to break in pieces having the shape of a rhombohedron.

Rugosa—The extinct order of anthozoan cnidarian corals that were sessile, marine, calcareous, generally cone-shaped, solitary, and distinguished from each other largely by features relating to their septa.

Sabkha—A coastal region subject to extensive flooding and evaporation, typically resulting in the deposition of salts; a salt flat.

Sarcopterygia—The subclass of Osteichthyes consisting of lobe-finned fish and tetrapods.

Schizochroal—Pertaining to a type of trilobite eye in which its visual surface consists of a number of biconvex lenses, rounded or polygonal in outline, each lens covered by an individual cornea and separated from others by sclerotic walls.

Schott—In conulariids, a transverse wall in the apical region of the periderm; may have been a repair structure produced in response to mechanical severance of the body.

Sclerite—A sclerotized structure or section of one that adds rigidity and may serve other functions in various animals, especially arthropods; examples include a cephalopod's beak and a lobster's exoskeleton, which is composed of many sclerites.

Sclerotized—Hardening of the cuticle of an organism, such as an arthropod's outer covering or the human fingernail, whereby a more rigid organic substance, especially sclerotin, is produced.

Scolecodont—The chitinous jaw of a polychaete worm.

Scyphozoa—The class of the Cnidaria whose members are marine and, unlike medusoid Hydrozoa, have stinging cells on their tentacles, lack a vellum, and typically have a four-partitioned body and medusoid adults.

Sea pen—A member of the anthozoan order Pennatulacea, named for their resemblance to quill pens.

Segment—The exoskeleton of a somite, generally of the thoracic region of an arthropod.

Septum (pl. a)—A calcareous partition between the chambers of certain cephalopod shells, such as nautiloids, the extinct ammonoids, and other cephalopods that bear an exterior shell. Also, in certain anthozoans such as rugose corals, a radially disposed longitudinal partition of a corallite.

Sessile—Attached to the substrate, incapable of self-propulsion.

Sicula—The skeleton of the initial zooid of a colony of graptolites.

Silica—The colorless mineral SiO_2 , belonging to the hexagonal crystal system and one of the most abundant minerals in Earth's crust; includes the familiar quartz, chert, and other lesser known morphs.

Siliceous—Composed of or containing silica.

Silicified—A type of fossil preservation in which the skeletal remains are replaced by silica.

Silurian—The period in the Paleozoic Era between the Ordovician and Devonian Periods, ranging from about 445,000,000 to 419,000,000 years ago.

Siphuncle—In externally-shelled cephalopods, the long slender or thick tube extending through all chambers to the apex and consisting of soft and shelly parts.

Somite—A transverse division of the body of an arthropod.

Species—Generally the lowest rank in taxonomic hierarchy, below genus; may be subdivided into subspecies or varieties. Members

of the same species are normally capable of breeding and producing fertile offspring, in contrast to members of different species.

Sphalerite—The mineral zinc sulfide (ZnS), in the cubic crystal system, and often of a brown to black, though variable, color; frequently found in octahedral form and associated with other sulfide minerals and calcite.

Spionida—An order of tentacle-bearing polychaete worms.

Spiracles—Small openings on the summit of the calyx of blastoids through which it is believed water was passed for respiration.

Spire—In gastropods, the volutions of the shell past the first volution, generally described in terms of its relative height, with spire height generally increasing with successive volutions.

Sporangia—Structures within which spores are produced.

Stalk—An elongated structure between an eye and the rest of the body, as in malacostracans, or between the rest of the organism and the substrate to which it is attached, as in conulariids and crinozoans. See Column.

Stipe—In graptolites, one branch of a branched rhabdosome or the entire colony of an unbranched rhabdosome.

Stratigraphy—The study of the successions of layered rocks, what they reveal concerning changes that have taken place at that region, their use in correlating with successions in other regions, and helping locate mineral deposits of economic interest.

Stromatolites—Laminated dome-like, sheet-like or branching structures comprised of finely laminated calcareous layers formed by cyanobacteria, contributing to free oxygen production and reef-building since Precambrian time.

Stromatoporoidae—An enigmatic extinct group of colonial, calcareous major reef-builders in the Paleozoic Era consisting of laminae and pillars; may have been poriferans (sponges).

Suspension-feeder—An organism that feeds on materials that are suspended in the water.

Suture—In externally-shelled cephalopods, the line of junction of the free part of the septum and inner side of the shell wall.

Symbiosis—A relationship between individuals of two species of organisms in which at least one species benefits; the relationship may benefit, harm or have no effect on the other species.

Tabula (pl. ae)—In rugose and tabulate corals, transverse partition of the corallite, extending to the outer wall or inner marginal wall.

Tabulata—The extinct order of almost exclusively Paleozoic, marine, calcareous, colonial, anthozoan cnidarians characterized by their exoskeleton of slender tubes crossed by many tabulae.

Taxon (pl. a)—Any unit used in the formal classification of organisms; e.g., kingdom, order, species, division, etc.

Tegmen—In crinoids, the adoral part of the theca above the origin of free arms or occupying the space between them; may be calcified or not.

Teleostomi—The grade of gnathostomes that includes the classes Acanthodii and Osteichthyes; have three pairs of otoliths.

Tentaculitida—The order of the Tentaculitoidea that had shells that were typically small (1–80mm), conical in shape, had transverse rings and, in some species, transverse and/or longitudinal striations—the transverse ones being growth lines.

Tentaculitoidea—An extinct group of enigmatic, generally marine animals that bore a conical or spiral calcareous shell and included the suborders Tentaculitida, Microconchida, and Cornulitida.

Terrestrial—Living exclusively on land.

Theca (pl. ae)—In graptolites, the sclerotized tube or cup enclosing any zooid of the rhabdosome other than the sicula. In crinozoans and echinozoans, the cup-shaped or globoid plated test of the animal enclosing the main part of the visceral mass; the cup (calyx) of a crinozoan, especially of a blastoid.

Thiensville Formation—The Middle Devonian formation that underlies the Milwaukee Formation.

Trace fossil—The fossilized markings or structures made by the activity of an organism on or within a substrate or another organism; the fossilized evidence of the locomotion, movements, industry, or other behavior of an organism, as opposed to the organism itself; includes, tracks, trackways, burrows, borings, resting traces, nests, feces, etc.

Tracheophytes—Vascular plants.

Triassic—The first period in the Mesozoic Era, ranging from about 250,000,000 to 200,000,000 years ago; followed by the Jurassic Period.

Trilobita—The common and extremely diverse subphylum of marine Paleozoic arthropods characterized by a calcite-impregnated exoskeleton divided longitudinally into three lobes.

Turbid—A condition of water in which particles are suspended, thus lowering clarity and light transmission.

Unconformity—A plane of contact between two successions of strata, representing a hiatus in the geologic record due to erosion and/or non-deposition of sediment.

Vagile—Free to move about.

Ventral valve (=pedicle valve)—Valve through which pedicle commonly emerges, usually larger than dorsal valve and invariably containing teeth when present.

Vermiform—Having the form of a worm.

Vug—A cavity in a rock typically formed by disintegration or dissolution of an embedded organism or other structure, and often partially or completely filled with a mineral of a different composition than the surrounding rock.

Water vascular system—In echinoderms, a hydraulic mechanism consisting of an assemblage of canals and associated specialized structures used to assist in feeding, locomotion, respiration and other important functions.

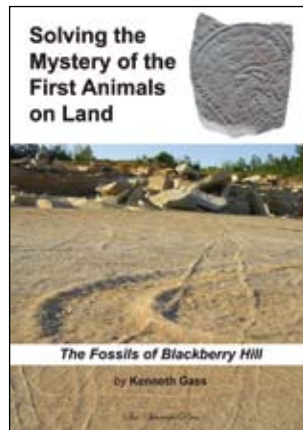
Whorl—One 360-degree rotation of a spiral shell such as that of many gastropods.

Zoecium—The skeleton of a bryozoan zooid, consisting of calcareous layers of zooidal walls and any connected intrazooidal calcareous structures.

Zooid—In graptolites, the soft-bodied individual inhabiting the theca. In bryozoans, one of the physically connected, asexually replicated morphologic units which, together with multizooidal parts and any extrazooidal parts present, compose a colony.

Zoarium (pl. a)—A colony of bryozoans.

Also by Kenneth C. Gass



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Reviews

Newsletter of the Paleontological Society (Priscum, Fall 2017, pages 19–20): “The photographs of the traces are extraordinary in their definition and clarity, and bring to life most vividly the activities of the animals. These trace fossils are of the greatest importance, as they are direct evidence that the beginnings of animal life leaving the sea for life on land began during the 540-500 million years of the Cambrian period, and not many millions of years later during the Silurian and Devonian periods.”

Newsletter of the Palaeontological Association (2016, number 91, pages 107–108): “To cite the author from his first line of the preface to the book: ‘A picture book on Blackberry Hills was inevitable. The place is simply too intriguing to remain buried in scientific journals...’ I couldn’t agree more.” ... “... an excellent introduction for readers who want to dig deeper into the topic and the technical literature. Based on this I would recommend this book to all with an interest in natural history, scholars as well as amateurs.”

Fossil News (Fall 2016: 51, abridged snippets): “...a beautiful, extensively illustrated book on one of the more important Middle Cambrian trace fossil deposits in the United States (the book contains 81 high-quality figures, most of them in colour and published only in this volume). ...a great addition to the library of anyone interested in trace fossils, Cambrian life, or the early invasion of land. For professionals, the book offers excellent images of the trace and body fossils of Blackberry Hill, as well as an extensive reference list. For amateur paleontologists, it provides a nice introduction to the importance of trace fossils in the fossil record (and includes a thorough terminology section, which helps with understanding the geological, ichnological and biological terms used throughout the text).”

Niles Eldredge, evolutionary biologist: “A mystery revealed, this book charmingly tells the story of how clever scientific detective work has answered the question of what those first animals to visit the subaerial environments of our world really were – however fleeting their visits from their ancient ocean habitats may have been. Engagingly told by Chris Gass, one of the key participants, the story reveals the importance of a highly special area that holds the fossilized evidence that shows what really happened.”

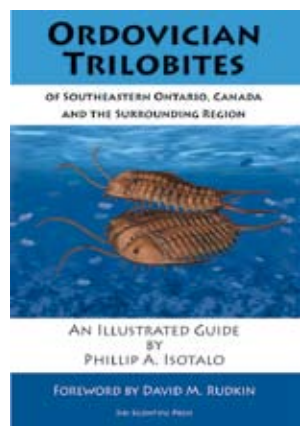
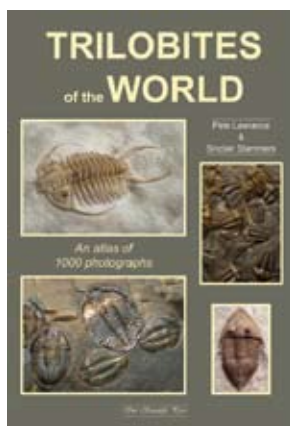
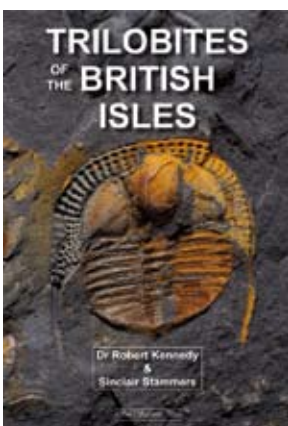
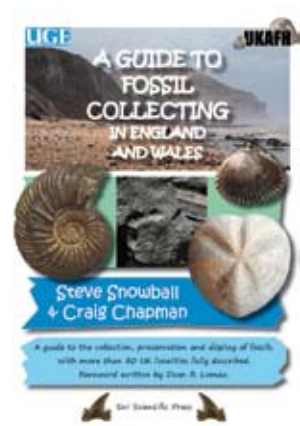
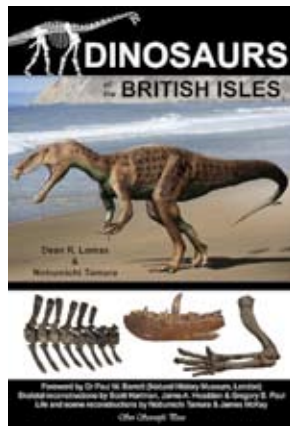
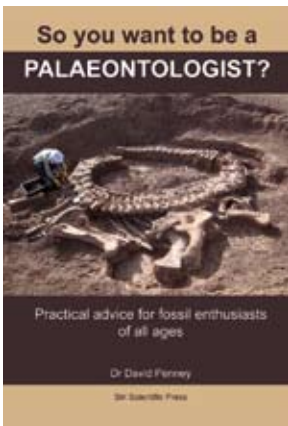
Gregory D. Edgecombe, The Natural History Museum (London): “The early history of life on land is a conundrum that has perplexed some of the foremost figures in the history of paleontology since the era of Richard Owen and Charles Darwin over 150 years ago. At centre stage in this mystery are trackways on sedimentary rocks that we now know are of Cambrian age - some 500 million years old - and were made by animals making the first excursions out of water in life's history. Here, Chris Gass weaves together the history of science and groundbreaking research conducted over the past 20 years to reveal the identities of these ancient trace makers. His book is a scientific detective story in words and photographs.”

From the back cover

Solving the Mystery of the First Animals on Land: The Fossils of Blackberry Hill is the first book to cover the unique group of rock outcrops in central Wisconsin that appears to have put an end to a 150 year-old mystery of global interest. Since the mid-1800s, fossilized trackways and footprints have been found on beach deposits that date back to the Cambrian Period, some 500 million years ago in what is now North America – but fossils of the animals that made them were reluctant to reveal themselves. Thanks to Blackberry Hill, the identity of some of the first animals to walk on land is a secret no more.

Numerous color photographs of spectacularly preserved tidal flat trackways, animals, and parts of the habitat itself, all set in stone, help to tell the story of some of the first animals to explore this strange, new, and presumably hostile environment. Current interpretations made possible by the fossil discoveries are presented, including how some of the trackways were made and what might have lured the animals ashore. Peculiar, winding trackways from giant, slug-like organisms and other boneless animals are shown covering entire surfaces. This book also reveals other surprises discovered at Blackberry Hill, including body and trace fossils of another tidal flat dweller never before found in rocks as old as these, and the first evidence showing that large jellyfish were abundant in Cambrian times and were already subject to mass strandings. In this book, Kenneth (Chris) Gass thus demonstrates why Blackberry Hill holds a special place in the history of life on Earth.

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